THE
ASTROPHYSICAL JOURNAL
AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOLUME XXII DECEMBER 1905 NUMBER 5

THE ARC IN HIGH VACUA

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INTRODUCTION

If a discharge tube is made with the electrodes placed opposite and extending very close to each other, e. g., 1 mm apart, one may observe the following phenomena as the pressure is gradually reduced. With pressure of the order of 1 mm of mercury, the current passes in the form of the ordinary purple glow. As the pressure is lowered, the luminosity of the gas decreases, and there is a noted increase in the potential difference necessary to cause the discharge to pass. This last fact is strikingly illustrated in the classical experiment of Hittorf.[1] Professor Thomson, in his theory of the discharge through gases, has shown that the potential difference necessary to produce the discharge in a vacuum tube must become very much greater if the distance between the electrodes is made less than the length of the negative dark space at the existing pressure. If the potential difference between the electrodes is still further increased by putting a spark-gap in series with the tube in the circuit leading to the electrical machine, cathode rays are given off strongly even at a pressure of 1 mm. When a pressure of a few thousandths of a millimeter is reached, if the external spark-gap is increased to 2 or 2.5 cm, the profuse cathode discharge and the attendant phosphorescence over

[1] *Wied. Ann.*, **21**, 96, 1884.

the surrounding glass walls vanish, and the current passes in the form of a brilliant spark or arc between the electrodes.

Soon after the discovery of the Roentgen rays, Professor Rowland,[1] in the course of some experiments on the source of the radiation, noticed in one of his tubes, having aluminium electrodes about 1 mm apart, that when the pressure was extremely low, the discharge passed as a "spark or arc" between the electrodes. He observed that the spot of light on the anode was the seat of very strong Roentgen radiation. Professor R. W. Wood,[2] working independently, published about this time a paper on "A New Form of Cathode Discharge and the Production of X-Rays, together with Some Notes on Diffraction," in which he noted many of the properties of the discharge and mentioned some points deserving further study.

GENERAL STATEMENTS

Before taking up in order the several lines along which this investigation was directed, I shall give a brief description of the arc as I have produced it. Then I shall indicate the view which I was led to take concerning the nature of the discharge. Thus will be made apparent the points chosen for special study, the results of which have substantiated the view adopted. There will also appear the grounds on which I have chosen to speak of the discharge as an arc, although it is of course intermittent.

The electrode which I have found to give the most intense light are platinum beads about 1.5 mm in diameter, easily made by fusing the end of a platinum wire in the oxyhydrogen flame. If the vacuum is good, say a few thousandths of a millimeter, and the beads are placed 2 or 3 mm apart, the cathode rays go off in every direction from the negative electrode, but principally in the horizontal plane normal to the cathode wire and containing the negative bead. If now a spark-gap of 2 or 2.5 cm is introduced in the circuit leading to the machine, and the electrodes are brought nearer together, when they are within about 1 mm of each other, the phosphorescence on the walls of the vessel vanishes, and there appears the brilliant light on the anode bead.

But while under these circumstances there was no phosphores-

[1] *Physical Papers*, p. 574. [2] *Physical Review*, **5**, 1, 1897.

cence on the walls of the outer tube, there was a bright glow on the small capillary tube into which the anode wire was sealed (see Fig. 3), extending several centimeters beyond the seal. This phosphorescence on the anode tube did not appear at relatively high pressures, but only when the pressure and distance between the electrodes were such as to cause a very high potential difference—i. e., only when there was a strong electric field around the electrodes. It was also observed that when this glow first became distinct on the anode tube, there was often a faint glow on the cathode tube also, but this did not persist at very low pressures or when a wide external spark-gap was introduced. A tube having platinum-wire electrodes sealed into bulbs joined by a capillary showed that when the potential difference between the electrodes was not too high, cathode rays were given off with very rapid alternations by each wire, principally by the normal cathode, and less by the electrode joined to the positive pole of the machine. The discharge from the machine was therefore under these conditions oscillatory, as was shown also by a telephone placed in the circuit. Thus the occasional appearance on the cathode tube of the phosphorescent glow, such as persisted on the anode tube, but nowhere else when the potential difference between the electrodes became very high, was due to its being temporarily an anode. The persistent phosphorescence on the anode tube is due, I think, to two causes. Some cathode rays shot off from the cathode toward the anode do not strike the bead, but go just by its edge, and, moving parallel and very close to the anode wire and tube, are drawn in by the very strong field about the tube and so strike against it, causing the phosphorescence and a feeble emission of Roentgen rays. Moreover, there is a small quantity of gas present in the vessel, and gas is being given off continually by the beads, particularly by the anode, which suffers disintegration, so that the pressure about the electrodes is probably appreciably higher than the average pressure in the system which is registered by the gauge. Since this gas about the electrodes, and especially in the region around the positive wire and tube, is ionized by the cathode rays which go past the positive bead, we may expect that the electrons or negative particles thus set free will be drawn in toward the anode, and in moving through the high potential gradient near the anode tube will acquire sufficient energy to cause

phosphorescence. Such an accelerating action of the positive electrode on the cathode rays is illustrated in many Roentgen-ray tubes, where it is found that the emission by the anti-cathode is markedly increased if this is made the anode or is joined with the anode. In fact, instances may be cited in which the anti-cathode gave no evidence of even a feeble Roentgen radiation unless it was made anode, in which case it became a strong source. If the above explanation of the glow on the anode tube is correct, we should expect that any screen or obstacle, placed in close to any part of the anode wire or tube so as to obstruct a section of those cathode rays which pass by the anode beads, would produce at most only a shading in the glow on the tube, and not a complete shielding; for there would still remain the effect due to the electrons set free in the surrounding gas by the stray cathode particles.

After the arc has commenced to pass steadily, the distance between the electrodes may be increased to 1.5 mm, provided the vacuum is maintained by pumping (for the evolution of gas by the electrodes is considerable). Under these circumstances, which are the most favorable for observing the discharge, the source of light has not the form of a continuous line reaching from one bead to the other, as is the case with the ordinary spark, but rather looks like a crescent on the outer or near surface of the anode. The accompanying drawing will make my meaning plain. This brilliant light is usually surrounded by a sort of halo or corona, the color of which depends on the metal of the anode. This halo was most marked with a magnesium anode, and was of a yellowish-green color. If the discharge runs for some time, the end of the anode is markedly disintegrated. Red-hot particles are shot off from the end of the anode in every direction. This effect was most striking in the case of a titanium anode, when the luminous particles were shot off in great numbers, and often suffered several reflections from the walls of the vessels while still glowing. This disintegration of the anode is of course more marked for the volatile metals. There is also a deposit on the end of the cathode, and the amount of this deposit is apparently proportional to the loss of the anode. Two especially well-formed deposits and craters were noticed with a platinum cathode and magnesium and iron respectively as anode. I give in Fig. 2 a sectional view of the anode and cathode, before the discharge and after it had run

for about two hours. If the vacuum was about 0.001 mm and the external spark-gap was closed so that the discharge became less intermittent, the anode bead was intensely heated; the small platinum bead could thus be raised to a white heat in a minute or less. This heating of the anode is of course only an example of the well-known action of cathode rays on any obstacle against which they strike. If the discharge is intermittent, there is time between the showers for the heat to pass off by radiation and conduction along the wire. Again, if the pressure is not extremely low, the potential gradient is not great enough for the cathode particles to be given sufficient energy to cause visible heating by impact. If the anode, instead of being a bead on a small wire, was a small bar of metal 1.5 mm in diameter, no visible heating effect could be produced, conduction in this case being too rapid.

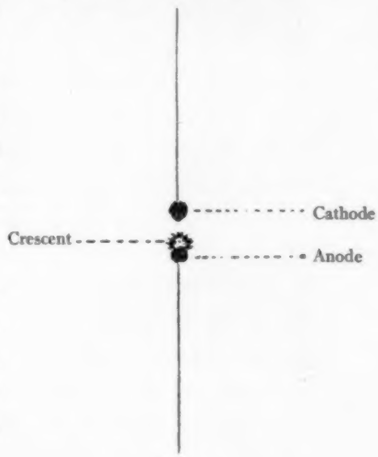

FIG. 1

Having observed that the anode wastes away as in the ordinary arc, that the light belongs to the anode rather than to the two electrodes equally, that it is much more intense than the ordinary spark in air between the same electrodes with the same source of current, that the anode is (under certain conditions) visibly heated, I have

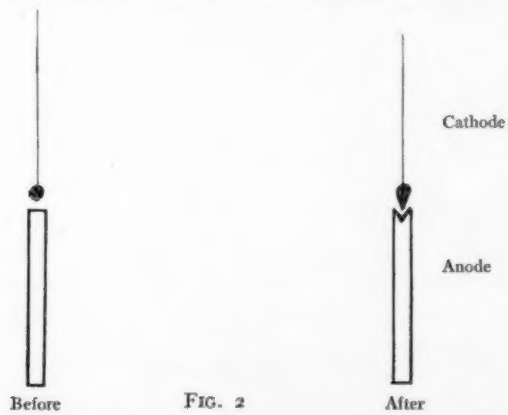

FIG. 2

chosen to designate the discharge by the word "arc"; not meaning that I consider it similar to a uniform steady arc, but rather that it is in these respects analogous to the arc, and, when the anode is markedly heated, possesses the essential characteristic of the arc. The fact that the light is emitted by the bombarded anode, and that the luminosity as well as the heating of the anode seems to be due to the violent impact of the cathode particles, makes it plain that the discharge cannot be strictly an arc or a spark, for no such conditions exist in either as they are commonly produced. The phenomena might seem to approximate more nearly to a possible state of things in the chromosphere, where we may think of the matter as suffering severe impacts of the small parts against each other, due to the falling in, under the Sun's attraction, of material from the outer portions. Hence it was that I have studied the spectra of such substances as show strong chromospheric lines. Moreover, from the experiments of Hartmann[1] and others it appears that the conditions for the existence of the so-called characteristic spark lines are fully met in this case, so that we should expect in advance to find these, whether or not there are also present characteristic arc lines.

OBJECT OF INVESTIGATION

In the study of this discharge the points which seemed to merit special investigation were:

What becomes of the cathode rays when the profuse phosphorescence on the walls of the tube vanishes and the brilliant little arc appears?

What is the action of a magnetic field on the arc?

Is there any change in the current when the above-mentioned change in the discharge takes place?

What is the nature of the spectrum of the light emitted—does it correspond in general to the characteristic spark or arc spectrum, and is the character of the lines at all similar to the corresponding chromospheric lines?

APPARATUS

The vacuum was produced with a Geissler-Toepler mercury pump, and the pressures were read with a McLeod gauge. The source of current was always a six-plate Toepler-Holtz electrical machine.

[1] *Astrophysical Journal*, **17**, 270, 1903.

This was used rather than a coil, since such a machine gives a practically constant potential and unidirectional current. If working under favorable weather conditions, the current from the machine was about 0.15 milliampere on closed circuit and 0.1 milliampere with an external spark-gap of 2.5 cm in series with the tube. These readings were made on a Roentgen ammeter, kindly furnished by the Roentgen Manufacturing Co. of Philadelphia. It was in every case necessary to have one of the electrodes movable, hence the discharge apparatus was always mounted on a glass tube about 85 cm long, dipping into a mercury basin. The lower electrode was sealed into a glass tube bent into the form of a U, one arm extending up the long glass tube in which the mercury formed a barometer column, the other being held in a clamp which was movable by a slow motion screw. The particular form of tube and other apparatus depended on the experiment in hand, and will be described in connection therewith.

EXPERIMENTS ON CATHODE RAYS

The vacuum apparatus used in all experiments in this connection was a small bell-jar, 8 cm in diameter and 20 cm high, fastened to a ground aluminium plate with stopcock grease (prepared according to the formula of Travers:[1] 1 part vaseline, $\frac{1}{8}$ part paraffin, 2 parts rubber. The lower electrode was always connected to earth. The platinum wires *P* and *Q*, on which were fused the electrode beads, were sealed into capillary tubes, as thin-walled tubing was often punctured by the discharge, which seemed to prefer a path of 10 or 15 cm to the very short one between the beads. The tube carrying the electrode *P* was sealed into the mouth of the jar *J* with Khotinsky wax, and the aluminium plate *A* was similarly fastened on to the barometer tube *H*. Through *H* there passes, alongside the electrode tube, a glass rod *R* bent into a U at the bottom, and at the top into a shape indicated in the figure, so that any kind of phosphorescent screen or obstacle could be mounted on this rod by being fastened on to a small piece of glass tubing which fitted rather snugly over the end of the rod. This cap could be made secure and rigid by a little wax warmed and put on the end of the rod as the cap was pushed down over it. The rod *R* is capable of a rather

[1] *Study of Gases*, p. 24.

wide vertical motion, so that any part of any mounted screen could be brought opposite either of the electrodes *P* and *Q*. A limited freedom of rotation of *R* about itself as axis made it possible to bring the screen up to the electrodes or to hold it quite out of the line of the discharge.

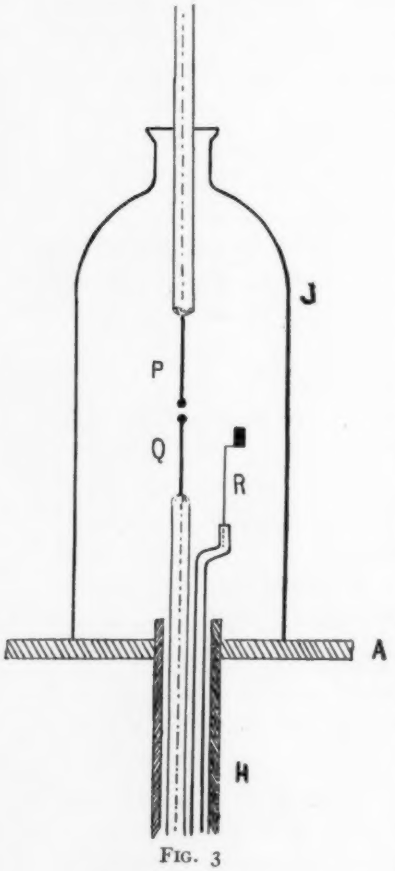

FIG. 3

Now, the very intense emission of Roentgen rays by the end of the anode very near to the cathode in a highly exhausted tube, as has been already alluded to, might seem to indicate a sort of focusing, so to speak, of the cathode rays on the anode surface just next to it. Moreover, some Roentgen-ray graphs taken by the writer with a pinhole camera seem to indicate that the surfaces most vigorously bombarded by the cathode rays during the arc discharge are the opposite surface of the anode, the wire, except just above the bead, and the more or less blunt end of the glass tube into which the anode wire is sealed. It may be remarked that on a plate obtained with a two-hour exposure at a distance of about 10 cm from the source there is no impression of the cathode, so that there seems to be no Roentgen radiation at the starting-point of the cathode particles. A distinct impression was made by the lower surface of the anode in three minutes.

Hence it was thought that, after the arc was formed, the distribution of the cathode rays was probably such as the following, viz.: the principal part of the discharge passes across directly from one electrode to the other, and the few cathode particles, shot out at a small angle with the vertical and going past the anode bead, are deflected by the electric field, which is very strong on account of the

extremely low pressure and the nearness of the electrodes. These are thus drawn in toward the anode, and so strike against the anode wire or the glass tube farther on. To test the views which I have indicated concerning the distribution of the cathode rays, and the cause of the persistent glow on the anode tube, the following experiments were made.

A small piece of copper foil about 5 mm square, and coated over with burnt ruby dust, which phosphoresces with a bright red color under the cathode rays, was mounted on the rod *R* (Fig. 3) with its plane vertical and perpendicular to a radius of the jar. By means of the rod the screen could be moved in a vertical or horizontal plane. Before the arc formed, if the screen was opposite the cathode bead or any part of that wire, there was a bright glow on the side of the screen next to the electrode and a weaker glow on the opposite side, the latter being evidently due to the diffuse cathode radiation from the walls of the jar. After the arc was formed there was no glow on the screen until it was moved up to or above the level of the upper bead, which was anode. In such a position, however, there was now a glow on the outside of the screen (though there was no radiation from the walls of the vessel) and none on the inside next to the electrodes. If the screen was moved up very close to the glass tube carrying the anode, there was a weakening of the phosphorescent glow on this tube, but not a complete shadow. A very strong phosphorescence was seen on the edge of the screen next to the cathode when the screen was so placed that its lower edge was opposite to or above the anode bead and was close in to the axis of the discharge. The fact that during the arc discharge there was, for the above-mentioned position of the screen, a glow only on the far side, shows that the cathode particles in the region are moving with appreciable velocity only toward the anode. This glow is thus due principally to the electrons generated in the region and drawn toward the anode by the electric field. The much stronger glow on the edge of the screen next to the cathode shows that, besides these secondary rays, there are some which come directly from the cathode against this edge.

Such a screen as was described above was then mounted with its plane horizontal. Before the arc passed, if the screen was on the

cathode side of the gap, there was a glow on the surface facing the gap. But if the arc was formed, there was no phosphorescence on the screen for such a position; but if it was moved opposite the anode wire or bead, and brought in very close to the wire, the glow appeared on the side facing the cathode; and this glow was much more intense on the parts of the screen nearest to the electrode wire. This was more marked if the screen was placed near the anode wire just beyond the bead. This screen, as the one above referred to, failed to cast any distinct or sharp shadow on the anode tube, which, as I have said, phosphoresced brightly for several centimeters beyond the seal of the platinum wire. This experiment also tends to confirm the opinion that some particles leave the cathode in a direction slightly inclined to the vertical and pass around the anode bead, but that most of them are confined to a region very close to the anode.

Besides the metallic ones, several mica screens were used, also screens or obstacles made of newly drawn small soda-glass wires. The phenomena were in each case similar to those of the experiments described above, and suggested the same explanation.

Now, with a fairly low pressure and small external spark-gap, it was often noticed that the phosphorescence on the bell-jar was confined to a narrow zone including the plane of the cathode bead, thus showing that the particles were shot out horizontally. As the necessary conditions for the arc were more nearly satisfied, the phosphorescent zone moved toward the anode end of the jar and became progressively less defined. The preceding experiments show that when the discharge passes as the arc, the cathode particles outside of the arc-gap are confined to the region close around the line of discharge and (excepting secondary radiation) are moving parallel to the discharge. It therefore seemed of interest to investigate whether there was a gradual change in the path of the rays from along a horizontal to a vertical direction.

A mica screen about 2 cm square, coated with ruby dust, was mounted with its plane vertical, and almost but not exactly containing the electrode wires. This gave sections of the cone of rays sent out by the cathode, and the shadow of a short glass wire which pierced the screen showed their path. Again, a mica disk mounted horizontally, and having a small hole in its center, could be placed

by means of the rod *R* in any desired position above or below the gap. As the cathode particles are at times shot out horizontally, and then, when the potential difference is increased, in a direction making an acute angle with the line joining the cathode to the anode, it was thought that the horizontal screen would indicate the angle at the vertex of the cone of rays from the cathode, and show whether this angle decreased continuously till the discharge passed as the arc; when, as already observed, no cathode particles make any large angle with the vertical. No result pointed to any other conclusion than that the change from the non-luminous to the so-called arc discharge was abrupt. There was no continuous and gradual concentrating of the rays along or nearly in the vertical, although the latter distribution always accompanied the arc. Furthermore, it was noticed that even when the mica disk was just opposite the end of the glass tube into which the anode was sealed, there still remained the phosphorescence for 3 or 4 cm along the anode tube.

I then determined to look more especially for the source of the persistent phosphorescence on the anode tube near to and just above the seal of the platinum wire into the glass. A small glass wire, about 1.5 mm in diameter, was bent into a ring large enough to go over the anode tube and leave a space of at least 1 mm all around. This was mounted on the rod *R* and, as the arc passed, was moved into various positions along the phosphorescent portion of the anode tube. Sometimes there seemed to be a faint shadow, but the cases were irregular and uncertain. Two little glass wires, about 3 mm long, stuck on to the anode tube radially, also failed to cast any distinct shadow along the tube. Bits of platinum wire gave similar results. The phosphorescence along the tube at points 2 or 3 cm from the end was then not caused principally by the glancing impact of rays shot out from the cathode and moving in paths only slightly inclined to the axis of the discharge.

Again, a thin glass disk, having in its center a hole just large enough for it to slip over the *Pt* beads, was mounted on the rod *R*. No position of this screen, whether just in the plane of the anode bead or quite up against the seal of this wire into the glass tube, gave any appreciable weakening of the glow on the anode tube. A small piece of glass tubing, 3 cm long and 2 or 3 mm larger in diameter

than the electrode tube, was mounted with the disk so that the two formed a sort of cap for the anode tube. This larger tube produced a very distinct shading, but there was still considerable phosphorescence on the protected or screened parts, although no primary cathode particles could strike the anode tube, and no secondary ones except such as were generated within the inclosing tube. The only explanation which occurs to me of the phenomena in question is that the glass surface of the disk and of the short outer piece of tubing, being struck by primary and also by secondary particles, emits into the inclosed space some radiations which, under the action of the strong field, bombard the anode tube and also act as ionizers. Since this space was very limited, the number of ions generated, and so the number striking against the anode tube, was smaller than if the tube had been removed, and so there was less intense phosphorescence than on portions of the anode tube that were not thus enclosed.

ACTION OF A MAGNETIC FIELD

In studying the action of a magnetic field on the discharge, the vacuum apparatus was a glass tube about 3 cm in diameter having a T-tube sealed into one side just opposite the electrodes and covered at its end with a glass plate sealed on with wax. In the first experiments to be described this side tube was normal to the plane of the axis of the magnet and the line of the discharge, and was 5 or 6 cm long, so that the glass plate would not blacken so rapidly with the platinum deposit; for the arc was observed through this side tube. The arrangement is shown in the drawing on the following page, except that the side tube is here a very short one along the axis of the magnet, which was a later arrangement. *N* and *S* are the conical pole-pieces of the electromagnet; these are bored through the center, so that when desired the arc can be viewed by looking along the axis *AB* of the magnet. A variable resistance in series with the exciting coils enabled the strength of the field to be altered at will. With low pressures, say 6 or 7 thousandths of a mm, if the external spark-gap was adjusted and the electrodes so placed that the arc was just on the point of forming—i. e., passed irregularly—the effect of the magnetic field was to cause the arc to pass regularly or steadily; the field seemed then to aid the formation of the arc discharge.

Again, the magnetic field often caused the anode bead to become visibly heated. Both of these actions may arise from the fact that a magnetic field in general hinders the discharge.[1] Here, then, its effect is to cause an increase in the potential difference between the electrodes, and is thus analogous to a lowering of the pressure.

As evidence of the fact that cathode rays have a very much higher velocity when the magnetic field is on, the following phenomenon may be mentioned. If the arc is not passing, but we have the phosphorescent glow over the tube, the magnetic field twists into spirals

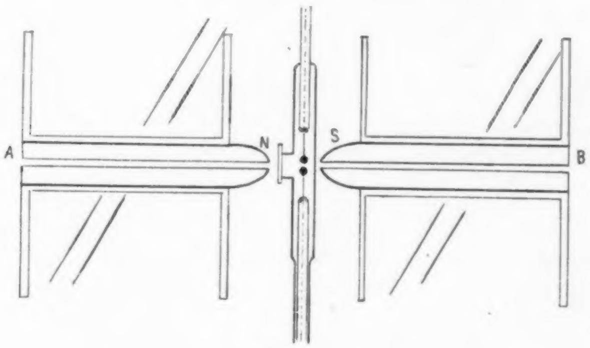

FIG. 4
(The oblique lines represent the Field Coils.)

the paths of all particles except such as are moving parallel to the field, and these therefore form on the tube a sort of image of the cathode. There thus remain two bright phosphorescent spots on either side of the tube, and the intensity of the glow is much increased in these images, as I call them. On cleaning the tube with aqua regia, it was found that in these places the glass appeared etched. It seems worth mentioning that this violent cathode discharge exerted some sort of deteriorating action on the walls of the tube around the discharge; for after a tube had been used for some days, it was found to crack very easily if put in the flame for any reason, and it was easy to break up the fragments of such a tube with one's fingers. I have never seen it stated that the glass of cathode tubes becomes specially fragile, and have no explanation to offer, but simply mention the fact.

As to a deviation along the normal to the plane of the electric and

[1] Thomson, *Conduction of Electricity through Gases*, p. 474.

magnetic force of the spot of light which marks the point of impact of the cathode particles, it need only be said that with such magnetic field-strengths as I could obtain, calculation showed that the possible deflection of the rays was less than could be observed, especially since the arc was not stationary, but wandered about over the anode slightly according as one part or another of the cathode was specially active.

It remains to be said that the magnetic field did not noticeably alter the distribution of the phosphorescent glow on the anode tube, though there was a slight weakening of the effect.

CURRENT MEASUREMENTS

Before I had the opportunity of using the Roentgen ammeter, I had made some readings with a small gas voltameter in order to see whether there was any appreciable variation of the current as the nature of the discharge changed. However, the current from the machine is very small and varies greatly with the weather conditions, so that I was not able to get any results which justified supposing that there was any material change in the current.

Measurements with the Roentgen ammeter did not show any change of current whether the discharge passed as the arc or whether there was the brilliant cathode glow over the tube, nor did the magnetic field have any readable effect. It is to be noted, however, that even a relatively large change in the resistance of the tube would make only a negligible change in the resistance of the whole circuit, including the machine itself, and that we do not have at hand a large souıce of current. Hence no large current changes should be expected for any of the variations which we have made in the conditions or nature of the discharge.

STUDY OF SPECTRUM

The spectrum of the discharge was produced with a Rowland concave grating of 60 cm radius. It was desirable to study specially the violet end of the spectrum, as most of the substances examined have the strongest lines in this region. Hence I used always a tube having a quartz window. The arrangement of the tube, slit, etc., is shown in the diagram. No lens was used, as the arrangement would have required a specially ground one of quartz, and very little would have been gained by it anyway. The time of exposure necessary

was about one or one and a quarter hours. The films used were Eastman Kodoid, orthochromatic. The form of the electrodes was for one a platinum bead, and for the other a small bar of the substance about 1.55 mm diameter, fastened in the end of a brass wire. This wire, about 3 cm long and having a screw socket joint in the middle was fastened rigidly to a heavy platinum wire sealed into the upper end of the U-tube. To change the electrode it was necessary only to lift off the bulb above the ground joint, unscrew the little brass end,

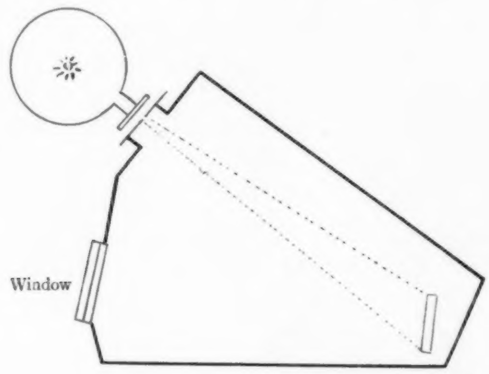

FIG. 5

and replace it by a similar one containing a different substance. For the calcium spectrum I used ordinary lime packed into a bored-out brass wire.

The first substances tried were *Mg* and *Pt* as anode and cathode respectively. There seemed to be no trace of *Pt* lines on the plate. It may be recalled here that I have said before that the light seemed to belong to the anode rather than to both electrodes; so I thought it worth while to test this point spectroscopically with two such metals as *Mg* and *Pt*, the one very easily volatilized and the other quite the opposite. I therefore carefully cleaned the *Pt* bead with acid and reduced the pressure to a few thousandths of a millimeter. If now the discharge was started with the *Pt* as anode, an exposure of as much as two hours failed to show any sign of the *Mg* lines. Of course, it was not possible to get the spectrum of the other electrode merely by reversing the current between exposures, on account of the previous deposit from the anode on the cathode. Nor was it possible to

reduce the pressure gradually and determine by eye observations at what pressure the anode only was active, for sufficient *Mg* got on the *Pt* anode to show in the spectrum even after the pressure was so low that the *Mg* cathode itself had ceased to play any part. In going from very low to higher pressures, the steps could not be made gradually, and so all that I can say is that so long as the pressure was low enough to cause the discharge to have the form of the little crescent of light on the anode, only the lines characteristic of the anode could be seen.

Having shown that the spectrum was characteristic of the anode only, if the discharge passed in the form which I have designated as the arc, I obtained the spectra of *Mg*, *Cu*, *Cr*, *Mn*, *Ti*, and *Fe*, respectively, by making anodes of these substances, the same *Pt* cathode serving throughout the series. Only the stronger lines made an impression on the plates in the time given an exposure; these, however, were amply sufficient for purposes of comparison such as I had in mind. The general character of the spectrum does not correspond to that of the arc or spark. (I could not take the ordinary arc or spark spectra on the same film with the spectrum of this anode light, and the intensities for these as given in the tables below are from Exner and Haschek.) Nearly all of the strong spark lines appear, and the spectrum is very much more like the spark than the arc. But the relative intensity is by no means the same for all the lines. Nor does there seem to be any close analogy between the intensities in this case and those of the chromosphere. There is observed here, however, an effect analogous to that brought out by Petaval and Hutton;[1] viz., certain lines have in this vacuum arc an intensity which is not at all in the same proportion to that of neighboring lines as in the ordinary arc or spark. It is doubtful if in this case the sole cause is diminution of pressure, but probably it is due both to the low pressure and to the fact that the luminosity is here excited under conditions materially different from those existing in the arc or spark in air.

I give below a list of the stronger lines showing on my plates, with their relative intensities in the ordinary arc and spark, chromosphere, and the arc as I have produced it in the vacuum tube. I shall designate these respectively by A, S, C, and Av.

[1] *Phil. Mag.*, **6**, 569, 1903.

MAGNESIUM

λ	Intensity A	Intensity S	Intensity C	Intensity Av	λ	Intensity A	Intensity S	Intensity C	Intensity Av
2777	20	6		2	2929	2	200		6
2778	20	5		1	2937	3	200		8
2780	30	10		3	3829	30	200	5	5
2782	20	5		1	3832	50	300	7	9
2783	20	6		1	3838	100	500	10	15
2791	5	100		12	4481	0	50	1	20
2796	200	500		10	5073				?
2798	2	100		8	5168			2	0
2803	100	500		8	5173			4	1
2852	500	100		8	5184			5	2

CALCIUM

λ	A	S	C	Av	λ	A	S	C	Av
3159	10	50		1	4289	50	20	5	0
3179	15	50		2	4299	30	20	1	00
3706	10	50	10	3	4303	100	50	2	3
3737	20	50	15	5	4308	30	20	5	0+
3934	500	1000	75	25	4318	50	30	1	1+
3969	300	500	60	20	4355	3	1		3
4227	1000	100	8	5	4435	100	20		1
4283	50	20	1	0	4455	200	30		2

CHROMIUM

λ	A	S	C	Av	λ	A	S	C	Av
2672	3	8		1	2980	2	10		2
2677	4	20		1	2985	2	10		1
2688	2	10		2	2989	1	10		1
2704	1	6		1	3016	2	3		1
2727	1	5		0	3027		8		1
2749	3	8		1	3041	4	10		2
2751	3	10		1	3050	1	10		2
2752	3	10		1	3119	3	10		1
2763	3	10		1	3120	3	15		2
2767	4	15		3	3125	3	20		3
2792		10		1	3132	4	20		4
2801	1	10		1	3147	2	5		0
2812	1	10		1	3368	3	20		1+
2818	1	8		0	3403	3	15		1−
2822	1	10		2	3409	1	20		1
2831	1	20		1	3579	30	20		2
2836	4	30		3	3594	30	20		2
2843	4	15		2	3605	30	20		2
2850	4	10		2	3964	6	8		1
2851	1	7		1	3970	5	8		1
2856	3	10		1	3977	6	8		1
2863	3	10		1	3984	4	5		1
2876	2	5		3	3993	3	3		0
2899	1	5		2	4254	50	50		4
2022	1	3		1	4275	50	30	1	3
2927		5		2	4290	30	30	1	3
2935	1	4		1	4337	10	8		1
2947	1	3		0	4345	10	10		1
2954	1	4		0	4352	15	10	1	2
2972	2	10		2					

MANGANESE

λ	Intensity				λ	Intensity			
	A	S	C	Av		A	S	C	Av
2576	4	30		5	2892	1	4		0
2594	4	15		4	2898	1	3		0
2606	4	10		4	2900	1	3		0
2610	1	8		1	2933	3	15		3
2618	2	8		2	2939	3	20		4
2626	2	7		2	2949	3	30		5
2633	1	7		2	3442	2	30		3
2638	1	5		2	3460	2	20		2
2640	1	5		1	3474	1	15		2
2656	1	4		0	3483	2	12		1
2667		4		1	3489	2	10		0
2702	1	5		2	3807	1	8		1
2706	1	8		2	3824	4	6		1
2709		4		1	4030	100	20		1
2712	1	5		2	4033	100	20		4
2719		3		1	4034	50	10		3
2795	50	4		2	4041	20	10		4
2805	1	5		1	4048	8	7		1
2813	1	3		0	4055	4	8		1
2815	1	3		1	4064	5	6		1
2831	2	3		0	4070	4	3		1+
2870	1	4		1	4235	10	20		1+
2880	1	5		1	4451	5	10		1+
2890	1	10		2					

TITANIUM

3168	5	15		0	3706	2	8		1
3191	4	10		0	3742	3	10		3
3202	3	10		0	3759	10	20		6
3234	8	15		2	3761	10	10		5
3236	5	6		2	3900	5	50		3
3239	4	6		2	3914	5	20		3
3242	4	10		1	4164	2	20		2
3249	4	10		1	4172	1	15		2
3262	4	15		1	4274	15	4		1
3323	5	10		2	4290	10	10		2
3329	6	10		1	4294	10	10		1
3332	3	8		1	4300	15	8		1
3335	5	10		1	4306	20	8		1
3342	4	10		2	4308	4	8		1
3349	8	10		4	4313	2	8	1	1
3362	1	30		3	4315	5	5		1
3373	4	20		3	4338	2	10		2
3384	3	20		3	4358				3
3505	3	30		3	4395	10	20		3
3511	3	30		3	4418	2	6	1	1
3520	2	8		1	4444	4	15	2	2
3536	2	15		1	4468	4	15	5	2
3625	2	8		1	4488	1	6		1
3641	15	10		1	4501	4	15	6	2
3660	3	10		1	4550	4	20	8	4
3662	2	10		1	4564	3	10	5	2
3685	8	100		5	4572	3	20	4	3

IRON

λ	Intensity A	S	C	Av	λ	Intensity A	S	C	Av
3735	50	10		1	4045	50	15	2	4
3749	30	10		3	4063	30	10		2
3758	30	8		1	4071	20	8		2
3763	20	6		1	4144	15	5		0
3816	20	10		0	4202	10	6		0
3820	50	10		1	4250	15	6		0
3826	30	8		1	4260	20	10	1	0
3841	15	5		1	4271	30	10		3
3860	30	6		1	4305	30	15		3
3878	15	5		0	4325	30	15		4
3886	20	5		1	4355		20		2
3928	15	4		0	4383	100	20	1	6
3969	15	5	1	0	4404	50	15	1	3
4005	15	6		0	4415	20	10	1	1

A comparison of these lists with those of Exner and Haschek will show that some strong spark lines are wanting on every plate, and many of the strong arc lines. With regard to the *Mg* group at λ 5183, it should be said that the small intensity given these is due to their being far in the green, where the plates were less sensitive. To the eye they appeared as strong as the line at λ 4481. It may be noted also that the *Mg* lines are much longer on the plate than those of any other substance. This is to be expected, as I have said before that the arc was surrounded by a much brighter halo with this metal than with any of the others. The strong *Hg* line at λ 4358 showed as a long line on every plate, the extensions above and below the arc being almost as bright as the central portion.

SUMMARY

The results of the foregoing experiments may be briefly summed up as follows:

If, at very low pressures, the discharge is caused to pass across a narrow gap, the cathode particles are shot off only by the near surface of the negative electrode, and almost all of them strike against the opposite face of the anode.

The principle action of a magnetic field on the discharge is to increase the potential difference in the gap, and consequently the kinetic energy of the cathode rays.

The luminosity of the anode is due to the violent impact of these cathode particles, and the spectrum of the light emitted is not analogous to that of either the spark or the arc. The fact that the spectrum is characteristic of the anode, and that the cathode makes no impression seems to merit special attention.

In conclusion, I wish to state that this research was carried on under the direction of Professor Ames. My best thanks are due to him for much valuable advice and criticism, and for the facilities placed at my disposal, and also to Professor Wood for many suggestions. The kindness and interest of student friends have been in many ways helpful.

Johns Hopkins University.

THE FIGURE OF THE SUN. II

By CHARLES LANE POOR

THE OBSERVATIONS OF SCHUR AND AMBRONN

Since my note, "The Figure of the Sun," was written, Ambronn has published, under the title of "Die Messungen des Sonnendurchmessers,"[1] an exhaustive research upon the shape and size of the Sun. This paper embodies the results of the solar investigations of Schur and Ambronn, made with the six-inch Repsold heliometer of the Göttingen Observatory, and extending over a period of nearly thirteen years, from 1890 to 1902. The conclusions drawn by Ambronn, from this great mass of observations, do not directly bear upon the theory advanced in my paper. A re-discussion of these observations was therefore undertaken, and some interesting facts were developed, tending to support and confirm the general results I had arrived at.

The idea that the diameter of the Sun may be variable is not new; a connection between the Sun's mean diameter and the sun-spot period has been suspected, and has been made the subject of several investigations in the past. When, therefore, the Repsold heliometer was mounted in Göttingen, Schur determined to investigate this subject thoroughly, and to make with that instrument a complete and uniform series of measures, which should extend over the whole of a sun-spot period. In carrying out this program, every conceivable precaution was taken to exclude systematic errors; in fact, two complete, parallel, and independent series of observations were made, one by Schur and one by Ambronn. Whenever possible, each observer obtained a series of four measures each week, two of the polar and two of the equatorial diameter. All the necessary instrumental constants for the reduction of these observations were obtained by each observer independently of the other. But the same methods and the same formulas of reduction were used in the two series; so that these series are directly comparable. The series of Schur extends from 1890 to the beginning of 1901; that of Ambronn,

[1] *Astronomische Mittheilungen der k. Sternwarte zu Göttingen*, Theil 7, 1905.

from 1890 to the end of 1902; both series thus covering an entire sun-spot period.

In reducing and discussing this great number of observations Ambronn investigates the questions of the figure and of the variability of the Sun separately. A brief résumé of his methods of investigating each of these points is given below, together with the conclusions he reaches in regard to these important questions.

1. *Variation of the Sun's diameter.*—Each series of observations is treated separately. Ambronn first finds the mean value of the Sun's diameter from all the observations of each series; then, subtracting this mean from the separate values, he finds the residual for each observation. From these residuals he finds the value of the mean residual for each year and tabulates these "yearly residuals," which thus show the yearly variation in the diameter.

In the first of these steps Ambronn was confronted with a difficulty: the series of observations were not strictly homogeneous. In October 1891 a prism was introduced into the instrument, in such a manner that the line joining the centers of the two images could always be brought into the same position relative to the eyes of the observer. This was to obviate any possible physiological influence which might cause the observer to measure the polar and equatorial diameters differently. An investigation, however, showed that the prism had a sensible effect upon the measures of all diameters, equatorial as well as polar. The diameters measured with the prism were all somewhat smaller than those measured without it. As the prism was used continuously after October 1891, the series of observations are divided into two periods by this date. The mean results from the observations in each period are given below, where the various values are expressed in scale-divisions, one division of the scale being approximately equal to 40″.

TABLE I

	Without Prism	Number	With Prism	Number
Schur	47.9919	25	47.9823	159
Ambronn	47.9819	27	47.9745	200

As a result of special measures made by Schur and Ambronn, both with and without the prism, Ambronn concludes that all obser-

vations made without the prism must be diminished by 0″.4, or 0.01 scale-division, in order to make them comparable with those made with the prism.

Correcting all the observations made without the prism by this amount, taking the general means, and reducing scale to arc, Ambronn finally obtains for the definitive values of the Sun's diameter at distance unity:

Schur	1920″.14	±0″.040
Ambronn	1919″.80	±0″.036

From these means the yearly residuals were found, and, as given by Ambronn, are tabulated below.

TABLE II

Year	Schur	Ambronn	Mean
1890	−0″.10	−0″.08	−0″.09
91	+0.03	−0.11	−0.04
92	+0.09	−0.08	0.00
93	+0.10	+0.06	+0.08
94	+0.10	+0.11	+0.10
95	−0.04	+0.25	+0.10
96	−0.10	+0.12	+0.01
97	−0.06	−0.12	−0.09
98	+0.01	−0.08	−0.04
99	+0.05	−0.06	0.00
1900	0.00	+0.02	+0.01
01	. . . . . .	+0.03	. . . . . .
02	. . . . . .	+0.09	. . . . . .

A simple inspection of these figures shows a certain periodicity. This is shown in the series of each observer and in the series of means. The periodic time of these variations is somewhere between six and eight years, and the amplitude about 0″.1. The large residual (0″.25) for the year 1895 is considered by Ambronn to be due to purely personal or accidental causes.

Ambronn further compares the curves which represent the above series of residuals with Wolfer's sun-spot curve for the corresponding years. The curve corresponding to the series of means is reproduced from Ambronn's paper and is given in Fig. 1, being the lowest curve of that figure. This curve, together with the above series of residuals, shows clearly, according to Ambronn, that there is no relation between the observed variations in the Sun's diameter and the relative frequency of sun-spots.

In considering these results of Ambronn, we note that he investigates the possible variation in the average or *mean* diameter of the Sun. The above residuals and the corresponding points on his curves are found by taking, in the series under consideration, the mean for each year of all the observations of both the polar and equatorial diameters. Thus his investigation would show whether there had been any change, periodic or secular, in the volume of the Sun, and not whether there had been any change in either the polar or the equatorial diameter. Changes in the relative sizes of the diameters of the Sun, or changes in its shape which do not alter its volume, could not be discovered by the methods used by Ambronn in this portion of his paper. His conclusions show that during the entire period of nearly thirteen years there was not present any periodic or secular variation in the Sun's volume, larger than that represented by a change of 0″.1 in the mean diameter of that body. This is not inconsistent with the views advanced in my paper. Ambronn merely shows that if the Sun be a vibrating body, it must so vibrate as to retain a constant volume, or a volume sensibly constant.

2. *The figure of the Sun.*—On each day of observation the polar and equatorial diameters were both measured twice, so that the research furnishes a great mass of data regarding the shape of the Sun. The values of the differences between the diameters, in the sense polar minus equatorial, are tabulated and given by Ambronn. From these are formed the mean values of this difference for each year; and from these yearly means, the mean value for the entire series of observations.

Unfortunately the tables of yearly means, as given by Ambronn, in Appendix 4, and also on page 44 of his memoir, contain errors, which mask the periodic character of this quantity. These yearly means were, therefore, all recomputed from the tabulated values of the daily observations, and the following corrections to Ambronn's computations were noted:

Page	108,	yearly	mean	1891	for	+0″.02	read	+0″.06
"	110,	"	"	1896	"	+0.05	"	−0.05
"	110,	"	"	1898	"	−0.11	"	+0.11
"	111,	"	"	1900	"	+0.04	"	+0.02

These errors are also found in the table on page 44, with the exception of that for 1896, where the correct sign is given.

As we have already seen, the observations during the first two years, 1890–1891, were made under instrumental conditions different from those during the rest of the interval. Ambronn, therefore forms the means of all the observations, and also means excluding these two years, to find definitive results. But as these results were obtained from erroneous yearly means, the final conclusions are also in error. I give below the final values as given by Ambronn on page 45 of his memoir, together with the corrected values:

TABLE III

MEAN VALUE OF THE DIFFERENCE (P.–E.)

AMBRONN'S RESULTS

	Schur	Ambronn	Mean
Mean of all observations................	$+0''.008$	$+0''.022$	$+0''.015$
Mean excepting those of 1890 and 1891...	-0.007	$+0.002$	-0.003

CORRECTED RESULTS

	Schur	Ambronn	Mean
Mean of all observations................	$+0''.030$	$+0''.022$	$+0''.028$
Mean excepting those of 1890 and 1891...	$+0.014$	$+0.002$	$+0.008$

These corrected results show the two series to be much more consistent than do the results derived by Ambronn. The final mean shows that the polar diameter exceeds the equatorial by $+0''.028$, and this value agrees closely with that, $+0''.038$, obtained by Auwers in "Die Venus-Durchgänge, 1874 und 1882."

The mean errors of the above results are given by Ambronn as

for Schur, $\pm 0''.015$;
for Ambronn, $\pm 0''.009$.

Comparing these with the values of the quantity (P.-E.) which he found, Ambronn concludes that the deviations are accidental, and that the Sun is sensibly a sphere. If, however, we compare these with the corrected values, we find that the values of Schur and Ambronn are each more than twice the size of their respective mean errors. The results can hardly, therefore, be considered as accidental.

In testing this result, Ambronn investigates the effect of the inclination of the measured diameter on the result to determine whether there was any tendency on the part of the observer to measure vertical diameters differently from horizontal. He could find no such

effect, but he calls special attention to the observations made during the two years, 1890–1891, which show the polar diameter to be decidedly the greater; and points out the fact that these results may be due to physiological causes, for during this interval no precautions were taken to obviate this difficulty. As has been noted, a prism was attached to the heliometer, in October 1891, in such a manner that all the diameters of the Sun were measured in the same relative position as regards the vertical, and from that date on the observations are perfectly homogeneous.

Ambronn also investigates the possibility of errors in the constants of refraction which were used in reducing the observations. In the winter months the Sun was at an average lower altitude at the time of observation than in the summer months. Hence, if there were any systematic errors in computing the differential refraction, such errors would be apparent when the observations are grouped according to the months in which they were made. When the observations are so grouped, no periodic variation is shown, and Ambronn concludes, therefore, that the constants and the methods used in computing the differential refraction are sensibly correct.

RE-DISCUSSION OF AMBRONN'S RESULTS

Making the corrections, already noted, to Ambronn's series of yearly means, we have the following series of values:

TABLE IV

Mean of Years (P.−E.)

Year	Schur		Ambronn		Mean	Weighted Mean	Wt.
	P.−E.	No. of Obs.	P.−E.	No. of Obs.	P.−E.	P.−E.	
1890	+0.13	10	+0.12	14	+0.12	+0.13	6
1891	+0.06	17	+0.14	14	+0.10	+0.10	6
1892	−0.06	12	+0.07	16	+0.005	+0.02	7
1893	−0.09	10	−0.01	14	−0.05	−0.07	6
1894	+0.10	11	−0.07	11	+0.015	−0.04	10
1895	+0.04	13	+0.03	15	+0.035	+0.03	9
1896	−0.05	19	−0.01	18	−0.03	−0.03	8
1897	+0.02	26	−0.04	21	−0.01	−0.01	13
1898	+0.11	21	+0.07	21	+0.09	+0.08	11
1899	+0.05	21	−0.03	24	+0.01	−0.01	12
1900	+0.02	24	+0.02	21	+0.02	+0.02	20
1901	+0.43	1	+0.06	27	+0.245	+0.07	10
1902	......	..	−0.06	15	−0.06	−0.06	5

In forming the weighted mean for the different years, weights were assigned to the observations of Schur and Ambronn in conformity with the values of the mean error, for each year, of a single observation, as given by Ambronn. Upon the assumption that the shape and size of the Sun are constant for each year, Ambronn found, from the separate observations made during that year, the value of the mean error of a single observation, and these mean errors are tabulated in Appendix 4. From these and the number of observations were found by the ordinary formulas the weights assigned to the yearly means.

While the determinations vary, a simple inspection of the above table shows that during the period from 1890 to 1902 there was a periodic change in the difference between the polar and equatorial diameters. This is clearly indicated in the series of observations of Schur, in that of Ambronn, in the series of unweighted means, and more clearly yet in the series of weighted means. In the earlier measures the polar diameter was decidedly the larger; in the years 1892, 1893, and 1894 the equatorial diameter was the larger; in the later years the polar diameter was again the larger.

These changes in the relative sizes of the polar and equatorial diameters are shown in the diagrams in Fig. 1. In this, No. 1 represents the relative frequency of sun-spots; the heavy curve being taken from the Greenwich observations and showing the proportionate area of the Sun's surface covered by spots; the lighter smooth curve being that of Wolfer's "sun-spot relative numbers." No. 2 shows the variation in the figure of the Sun, as represented by the yearly means of the observations of Schur and Ambronn; the unweighted and weighted means for each year being shown on the diagram. In this figure the dotted curve represents Wolfer's curve of sun-spot frequency, and this curve is identical with that in No. 1. In No. 3 are shown the observations of Schur and Ambronn; the heavy curve representing Ambronn's observations, the dotted curve those of Schur. No. 4 is Ambronn's curve, and this shows the variation in the mean diameter of the Sun as deduced from all the observations of both Schur and Ambronn.

Nos. 2 and 3 show clearly the changes in the shape of the Sun. The individual curves of Schur and Ambronn are similar; the posi-

tions of maxima and minima are nearly the same in both. The mean curve shows a general resemblance to Wolfer's sun-spot curve; both curves rise rapidly to a maximum in 1893, and then gradually

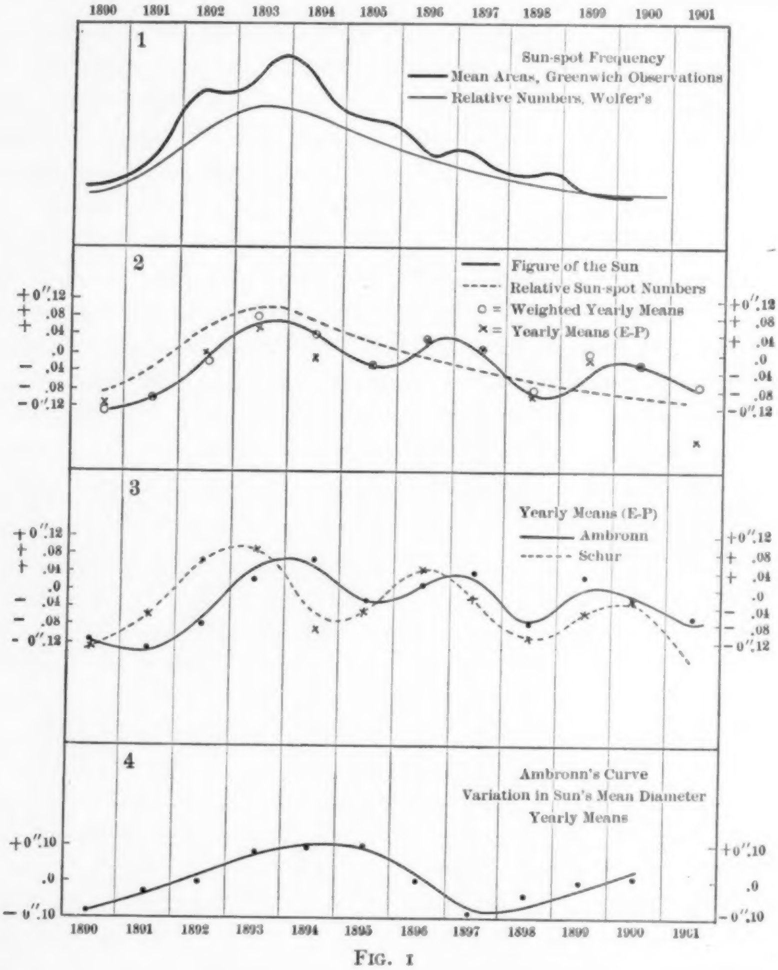

FIG. 1

fall off to a minimum in 1901. The figure curve shows, however, two subsidiary maxima in the years 1896–1897, and 1899. These subsidiary maxima do not appear in Wolfer's curve, but the first one is clearly indicated in the Greenwich sun-spot curve, which shows a decided maximum at the beginning of 1897.

From the curves in No. 2 may be found the residuals upon the supposition that the Sun is a sphere, and also upon the hypothesis that its figure varies with the number of sun-spots. Forming these residuals, we shall have:

TABLE V

RESIDUALS

Date	Sphere	Variable Figure	Date	Sphere	Variable Figure
1890........	−0.13	−0.04	1896.......	+0.03	+0.04
1891........	−0.10	−0.05	1897.......	+0.01	+0.05
1892........	−0.02	−0.07	1898.......	−0.08	−0.02
1893........	+0.07	−0.02	1899.......	+0.01	+0.08
1894........	+0.04	−0.03	1900.......	−0.02	+0.07
1895........	−0.03	−0.05	1901.......	−0.07	+0.03

From these we find for the sum of the squares of the residuals, on the two hypotheses:

	$[vv]$
Hypothesis of sphere,	0."0475
Hypothesis of variable figure,	0.0295

This shows that the hypothesis that the figure varies proportionately with Wolfer's sun-spot numbers represents these observations of Schur and Ambronn much better than does the hypothesis that the Sun is a sphere.

Thus these observations indicate clearly that the Sun's figure is subject to periodic changes, and they point toward the conclusion that the period of these fluctuations is the same as that of the sun-spot frequency. The amplitude of these variations, as shown by these observations, is extremely small, being not more than 0."2.

To test this question of the variability of the Sun's figure still further, I formed the means of the observed values of (P. − E.) for every three months, making the dates symmetrical with the position of the Sun's axis. On June 5 and December 6 the axis of rotation of the Sun is perpendicular to our line of sight, and on these dates the measures will give directly the polar diameter. The periods, therefore, in which the observations were grouped are as follows:

January	15—April	15
April	15—July	15
July	15—October	15
October	15—January	15

These means are tabulated below, being arranged according to the mean date of observation; the weights being simply the number of observations from which the mean is formed in each interval.

TABLE VI

MEAN OF EVERY THREE MONTHS (P.-E.)

Schur			Ambronn			Mean		
Date	P.–E.	Wt.	Date	P.–E.	Wt.	Date	P.–E.	Wt.
1890, May 31	+0.11	5	1890, June 14	+0.05	5	1890, June 7	+0.08	10
Oct. 1	+0.16	2	Aug. 22	+0.22	5	Sept. 2	+0.20	7
Nov. 17	+0.14	3	Nov. 17	+0.09	4	Nov. 17	+0.11	7
1891, Mch. 17	−0.08	4	1891, Feb. 28	+0.09	4	1891, Mch. 8	0.00	8
June 3	+0.30	7	June 2	+0.19	5	June 3	+0.25	12
Sept. 23	+0.09	3	Aug. 10	+0.18	3	Sept. 1	+0.14	6
Dec. 6	−0.37	4	Nov. 25	+0.04	2	Dec. 2	−0.23	6
1892, Apr. 1	−0.04	4	1892, Mch. 2	+0.09	6	1892, Mch. 14	+0.04	10
June 4	+0.05	4	June 4	+0.11	5	June 6	+0.08	9
Sept. 24	−0.27	2	Aug. 22	+0.10	3	Sept. 4	−0.05	5
Nov. 24	+0.38	1	Nov. 14	−0.10	2	Nov. 17	+0.06	3
1893, Mch. 24	−0.20	4	1893, Mch. 25	−0.14	4	1893, Mch. 27	−0.17	8
May 29	−0.05	5	May 29	+0.08	4	May 29	+0.01	9
Aug. 4	+0.09	1	Aug. 13	+0.04	2	Aug. 10	+0.06	3
1894, Mch. 24	+0.16	3	1894, Mch. 16	−0.09	3	1894, Mch. 20	+0.04	6
May 30	+0.14	6	June 30	−0.04	3	June 9	+0.08	9
July 24	−0.25	1	Aug. 19	−0.17	3	Aug. 13	−0.19	4
Dec. 10	+0.03	1	Nov. 23	+0.08	2	Nov. 29	+0.06	3
1895, Mch. 18	+0.08	3	1895, Mch. 6	−0.52	1	1895, Mch. 15	−0.07	4
May 31	0.00	8	May 30	+0.07	5	May 31	+0.03	13
July 16	0.00	1	Aug. 25	+0.05	7	Aug. 20	+0.04	8
Oct. 18	+0.27	1	Nov. 24	+0.16	2	Nov. 11	+0.20	3
1896, Feb. 10	−0.11	4	1896, Feb. 21	+0.14	4	1896, Feb. 16	+0.02	8
June 8	−0.27	7	June 8	−0.09	7	June 8	−0.18	14
Aug. 25	+0.09	3	Aug. 31	−0.05	5	Aug. 29	0.00	8
Nov. 22	+0.23	5	Dec. 19	+0.03	3	Dec. 3	+0.16	8
1897, Mch. 13	+0.06	4	1897, Mch. 14	+0.18	2	1897, Mch. 13	+0.10	6
June 6	0.00	10	June 1	−0.07	9	June 4	−0.03	19
Sept. 4	−0.03	8	Aug. 29	+0.05	4	Sept. 2	0.00	12
Nov. 8	+0.14	4	Dec. 12	−0.09	7	Nov. 30	−0.01	11
1898, Mch. 17	+0.07	4	1898, Feb. 28	+0.21	4	1898, Mch. 8	+0.14	8
May 29	+0.19	7	June 9	−0.08	6	June 3	+0.07	13
July 30	+0.12	5	Aug. 20	+0.07	6	Aug. 10	+0.09	11
Nov. 19	+0.04	5	Dec. 9	+0.06	4	Nov. 29	+0.05	9
1899, Feb. 23	−0.02	8	1899, Mch. 6	−0.06	7	1899, Feb. 28	−0.04	15
May 29	+0.07	7	May 31	−0.10	6	May 30	−0.01	13
Aug. 2	+0.14	5	Aug. 21	+0.09	7	Aug. 13	+0.11	12
Nov. 4	−0.04	1	Dec. 3	+0.02	3	Nov. 26	0.00	4
1900, Feb. 22	+0.12	7	1900, Mch. 8	+0.10	6	1900, Feb. 28	+0.11	13
June 1	+0.07	8	June 2	−0.01	8	June 2	+0.03	16
Aug. 28	+0.01	6	Aug. 23	−0.02	7	Aug. 25	−0.01	13
Dec. 8	−0.17	3	1901, Jan. 8	+0.45	3	Dec. 24	+0.14	6

An inspection of these means shows that the value of (P. – E.) varies very irregularly, jumping from large negative to large positive values. There is a break in the series during eight months during the latter part of 1893 and the early part of 1894. Thus the series falls into two parts. During the first part, from 1890 to the middle of 1893, the value of (P. – E.) was on the whole decreasing; the equatorial diameter increasing with respect to the polar diameter. This is shown by the observations of each observer and by the mean. In the second part, from 1894 to 1901, the value of (P. – E.) on the whole shows a tendency to increase; during this interval the equatorial diameter was shrinking relatively to the polar. The break in the observations is extremely unfortunate, for the sun-spot maximum, according to Newcomb, occurred in the latter part of 1893.

These results are exhibited in Fig. 2. The upper curve shows the variation in the spotted area of the Sun, as shown by the Greenwich observations; the second curve, the variation in the magnetic declination in minutes of arc; and the fourth curve, the variation in the vertical force of the Earth's magnetism. The curves are taken from *Monthly Notices, R. A. S.*, Volume **63**. The third curve shows the variations in the Sun's figure as plotted from the above table. This curve of the Sun's figure shows a general resemblance to all the other three curves. The resemblance to the sun-spot curve is as striking in case of the curve of figure as in that of the vertical magnetic force. Not only do the curves agree in their general characteristics, but in many cases the curve of figure shows subsidiary maxima and minima agreeing with those in the other curves. The figure curve shows a high maximum in the latter part of 1891. Similar maxima are found in the sun-spot and in the declination curves; similar coincidences in the maxima are found in the middle of 1894, the early part of 1895, the early part of 1896, and the latter part of 1897.

After 1898 the figure curve departs from the other three. During the years 1899 and 1900 the curve of figure is too high, it does not fall to so low a minimum as do the others, and the minimum appears to be somewhat earlier in this curve than in the other three.

These observations of Schur and Ambronn thus tend to confirm the general result given in my former paper. They seem to show that the ratio between the polar and equatorial radii of the Sun is

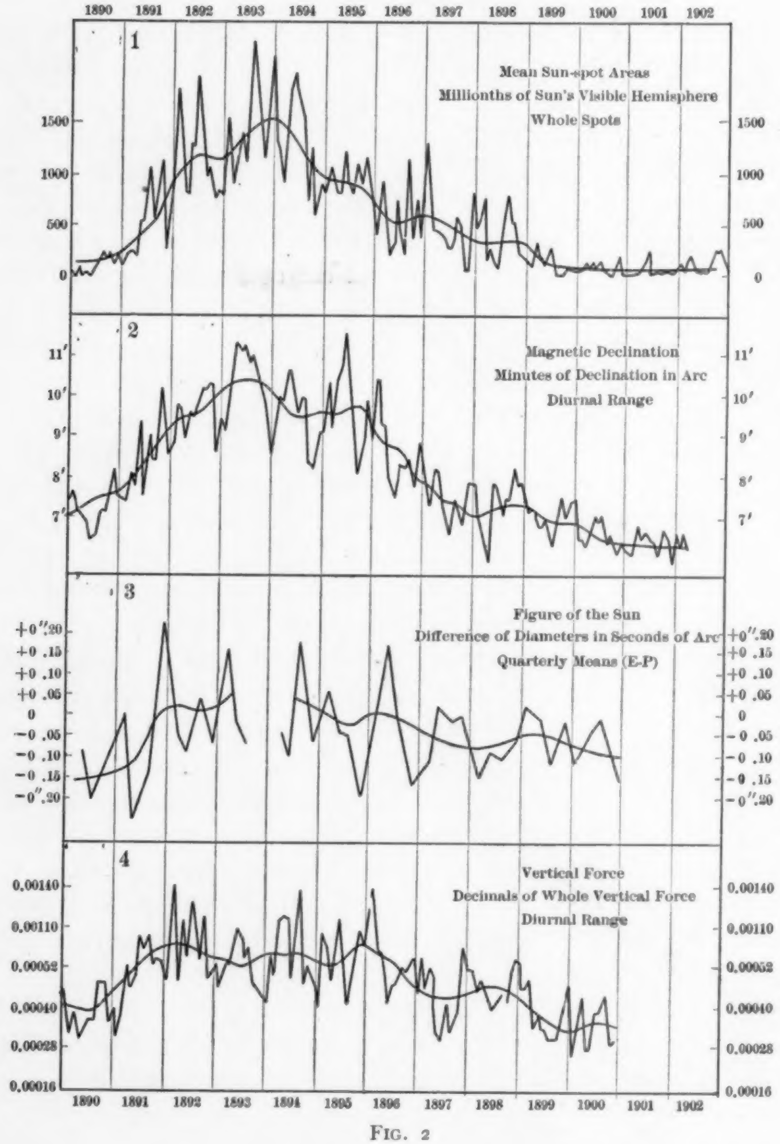
1890 1891 1892 1893 1894 1895 1896 1897 1898 1899 1900 1901 1902
1
Mean Sun-spot Areas
Millionths of Sun's Visible Hemisphere
Whole Spots
1500
1000
500
0
2
Magnetic Declination
Minutes of Declination in Arc
Diurnal Range
11′
10′
9′
8′
7′
3
Figure of the Sun
Difference of Diameters in Seconds of Arc
Quarterly Means (E-P)
+0″.20
+0 .15
+0 .10
+0 .05
0
−0 .05
−0 .10
−0 .15
−0″.20
4
Vertical Force
Decimals of Whole Vertical Force
Diurnal Range
0.00140
0.00110
0.00052
0.00040
0.00028
0.00016

FIG. 2

variable, and that this variability is periodic. The exact length of this period is uncertain, but it appears to be nearly the same as the sun-spot period. The amplitude of this variation is about $0.''2$; the difference between the largest positive and negative values being about $0.''5$.

These heliometer measures thus tend to supplement and confirm the conclusions originally drawn from the solar photographs of Lewis M. Rutherfurd. These photographs clearly show the figure of the Sun to be variable; but unfortunately they do not extend over a sufficient number of years to determine the period of this variability. On the other hand, the amplitude of this variation, as shown by the photographs, is considerably greater than that shown by the heliometer measures.

Columbia University,
October 1905.

OBSERVATIONS OF STANDARD VELOCITY STARS WITH THE LOWELL SPECTROGRAPH (1905)

By V. M. SLIPHER

In the present paper are given the results of my observations of the list of "Standard Velocity Stars,"[1] made with the Lowell Spectrograph during the summer and autumn of the present year. Owing to the circumstance that the time that the spectrograph is available for stellar radial velocity work is limited, I have not been able to follow closely the recommendation[1] that the three observations of each star be made at the beginning, middle, and end of the two months symmetrical about the date of the star's opposition with the Sun. Inasmuch as *α Crateris*, the faintest star of the regular list, has been, and will be for some time yet, too near the Sun for observation, I have substituted for it *γ Cephei*, the faintest star of the supplementary list, in order to bring these observations to an early conclusion. The ten stars that I have observed are, then, the following:

α Arietis	*β Ophiuchi*
α Persei	*γ Aquilae*
β Leporis	*ε Pegasi*
β Geminorum	*γ Piscium*
α Boötis	*γ Cephei*

I have secured, as was suggested, extra spectrograms of *α Persei* and *α Boötis;* and, in order to check the performance of the spectrograph, I have measured at frequent intervals the spectrographic velocities of *Venus, Mars,* and the Moon.

The spectrograph,[2] as employed in these observations, consists essentially of a collimator of 30 mm aperture and 490 mm focus, a train of three 63° dense flint prisms and a camera of 35 mm aperture and 471 mm focus, the whole inclosed in a box supplied with

[1] See Frost on "Coöperation in Observing Radial Velocities of Selected Stars," *Astrophysical Journal,* **16**, 169, 1902.

[2] A detailed description of this instrument was published in the *Astrophysical Journal* for July, 1904 (**20**, 1–20).

electrical heating. The construction of this instrument partakes of the universal type, having a device for automatically keeping the prisms in the position of minimum deviation, a feature almost indispensable in our varied program of spectroscopic work. But there is an insufficient number of clamp screws to hold the prisms rigidly without causing injurious pressure on the glass of the prisms, each prism being clamped by only one screw, which presses centrally upon the top plate of its mounting. When this screw is clamped too tightly, unequal pressure is transmitted to the prism, destroying its homogeneity. Although realizing that by so doing I was impairing the definition of the spectrograms, I have nevertheless turned down very tightly the clamp screws and thus insured the rigidity of the prisms. I have in this way obtained entirely trustworthy spectrograms, but, as might be supposed, the definition in the spectrum is rather inferior, being no better on Seed 23 plates than it should be on the coarser 27 emulsion. The full power of the spectrograph has therefore not been realized, and the agreement of the velocities from different lines of the same plate is not so close as it should be with a spectrograph of this size.

In these observations, the prisms have been used set at minimum deviation for wave-length 4415. The linear dispersion at different points through the part of the spectrum covered by my measures is as follows:

Wave-Length	Tenth-Meters per mm
4250	9.9
4300	10.6
4350	11.4
4400	12.3
4450	13.2
4500	14.1
4550	15.0

The star spectrum usually has a width on the plates of one-third of a millimeter, and is separated from the two parts of the comparison spectrum by about a tenth of a millimeter.

All the details relative to the making of the spectrograms are given in the accompanying table, which will be readily understood. The date of the observation is given in Greenwich Mean Time. Except in the case of a few of the short exposures, the comparison

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Object	Plate Number	Date, 1905	Length of Exposure	Slit-Width	Comparison Spectrum	Temperature Inside Prism-Box	Seeing Sky	Seeing Image	Seed's No. of Plates	Remarks
β Geminorum	L 1833	April 7d 17h 0m	57m	0mm.019	*Ti, Cr*	12°.47–12°.56			23	
α Boötis	L 1850	14 20 15	37	0.020	*Ti, Cr*	8.13– 8.18	Poor		23	
Mars	L 1868	28 18 42	70	0.020	*Fe, Ti, Cr*	11.43–11.43	3	3	23	
Mars	L 1881	May 18 16 30	72	0.022	*Mo, Fe*	15.00–15.02	3	3	23	
γ Aquilae	L 1921	July 5 21 5	120	0.025	*Mo,Ti,Fe,Cr*	24.73–24.76	4	2	27	Spectrograph readjusted
γ Aquilae	L 1926	7 20 25	128	0.028	*Mo, Fe*	24.72–24.70	4	2–1	27	
Venus	L 1937	11 0 21	8	0.018	*Mo, Fe*	22.38–22.45	3	3	23	
Moon	L 1944	13 18 35	36	0.020	*Mo, Fe*	19.26–19.15			23	
β Ophiuchi	L 1947	14 19 10	110	0.028	*Mo, Fe*	18.20–18.21			27 N. H.	
ε Pegasi	L 1948	14 21 18	90	0.028	*Mo, Fe*	18.20–18.23			27 N. H.	
γ Aquilae	L 1952	15 19 50	120	0.028	*Mo, Fe*	19.90–19.98	4	3	27 N. H.	
ε Pegasi	L 2007	Aug. 10 20 42	120	0.028	*Fe, V*	17.90–18.02	4	2	27 N. H.	Spectrograph readjusted
α Boötis	L 2011	12 16 6	40	0.020	*Fe, Cr, V*	19.40–19.55	5	2	23	
Moon	L 2013	12 19 28	30	0.020	*Fe, Cr, V*	19.50–19.40	5	4	23	
α Boötis	L 2016	15 16 8	40	0.020	*Fe, V*	21.20–21.18			23	
β Ophiuchi	L 2017	15 17 50	120	0.027	*Fe, V*	21.14–21.15			27 N. H.	
α Boötis	L 2043	29 15 34	40	0.024	*Fe, V*	21.37–21.55	4	1–2	23	Spectrograph readjusted
α Persei	L 2049	30 23 6	58	0.025	*Fe, V*	20.65–20.70	3–4	3–4	23	
α Boötis	L 2053	31 15 31	40	0.022	*Fe, V*	19.66–19.70	3	1–2	23	
ε Pegasi	L 2054	Sept. 6 18 48	120	0.028	*Fe, V*	15.70–15.74	4	3	27 N. H.	
β Ophiuchi	L 2058	8 16 32	120	0.028	*Fe, V*	17.56–17.56	3–4	1–2	27 N. H.	
α Arietis	L 2067	12 20 48	60	0.022	*Fe, V*	20.16–20.10	3–4	3–4	27 N.H.	
α Persei	L 2068	12 21 59	40	0.024	*Fe,.V*	20.10–20.13	3	3–4	27 N. H.	

JOURNAL OF OBSERVATIONS—*Continued*

Object	Plate Number	Date, 1905	Length of Exposure	Slit-Width	Comparison Spectrum	Temperature Inside Prism-Box	Seeing Sky	Seeing Image	Seed's No. of Plates	Remarks
				mm						
α Persei	L 2079	Sept. 25d 20h 49m	30m	0.025	*Fe, V*	13°10–13°10	4	3	27 N. H.	Spectrograph readjusted
ε Pegasi	L 2080	27 17 28	60	0.027	*Fe, V*	16.66–16.66	4	4	27 N. H.	
γ Piscium	L 2081	27 19 15	120±	0.029	*Fe, V*	16.67–16.63	3–0	4	27 N. H.	Clouds
α Arietis	L 2085	Oct. 2 20 8	50	0.020	*Fe, V*	13.62–13.68	4	3	27 N. H.	
β Leporis	L 2087	2 23 57	83	0.026	*Fe, V*	13.56–			27 N. H.	
Moon	L 2091	5 15 40	50±	0.020	*Fe, V*	18.17–18.11			23	Hazy
α Arietis	L 2094	5 18 54	50	0.024	*Fe, V*	18.10–18.14	3	3	27 N. H.	
Mars	L 2096	6 13 52	55	0.024	*Fe, V*	18.80–18.76	3	2	27 N. H.	
α Persei	L 2100	7 22 53	20	0.024	*Fe, V*	15.96–15.96	3–4	2	27 N. H.	
β Geminorum	L 2101	7 23 39	28	0.022	*Fe, V*	15.96–16.00	3–4	1–2	27 N. H.	Guiding interrupted
γ Cephei	L 2109	12 20 42	105±	0.027	*Fe, V*	13.98–13.95	4	3–4	27 N. H.	
β Leporis	L 2111	12 23 21	88	0.026	*Fe, V*	13.90–13.87			27 N. H.	
Venus	L 2113	13 1 15	12±	0.020	*Fe, V*	13.96–14.00			23	Clouds
β Geminorum	L 2117	15 1 5	20	0.023	*Fe, V*	9.60– 9.64	4	3	27 N. H.	
γ Piscium	L 2122	27 18 7	150	0.029	*Fe, V*	11.00–11.07	4	3–4	27 N. H.	Spectrograph readjusted
γ Cephei	L 2123	27 20 45	120	0.029	*Fe, V*	11.00–11.08	4	3	27 N. H.	
α Persei	L 2124	27 22 7	15	0.029	*Fe, V*	11.06–11.04	4	3	27 N. H.	
β Leporis	L 2125	27 23 17	84	0.029	*Fe, V*	11.01–10.94	4	3	27 N. H.	
γ Piscium	L 2129	Nov. 2 17 3	125±	0.029	*Fe, V*	8.90– 9.00	3–0–2	2	27 N. H.	Clouds
γ Cephei	L 2130	2 19 50	50±	0.028	*Fe, V*	9.12– 9.14	3–0	2	27 N. H.	Clouds

has been photographed at the beginning and end of the star exposure. The table gives in one column two readings of a large-scale thermometer whose bulb is inside the prism-box near the base of the middle prism. For the most part, the two readings are those made at the beginning and end of the exposure, but for the later plates they are the highest and lowest readings of the thermometer. The temperature control has worked well, and the range in the readings of the prism thermometer for the longest exposures ordinarily does not exceed 0°.1 C. and frequently is less than 0°.05. The double column headed "Seeing" gives the condition of the sky as regards transparency and the character of the stellar image, both on a scale increasing from 0 to 5, where 5 means perfection. The remark "Spectrograph readjusted" means that the spectrograph has been used for other lines of work requiring different adjustments, during the interval against which that note is placed. I have endeavored to keep all adjustments the same throughout this series of observations.

The electric spark has furnished the comparison spectrum. The induction coil supplying the high potential current receives its power from a 104-volt alternating current. A condenser is inserted in the secondary from the coil. To insure the complete illumination of the collimator lens with the light from the spark, a ground glass has been interposed between the electrodes and the slit.

Except for a few of the earlier plates, I have employed for comparison the spectrum of an alloy containing 10 per cent. of vanadium and 90 per cent. of iron. By occulting the twelve bright lines from λ 4379 to λ 4415 during the greater part of the exposure to the spark with a projection on the slide working in the end of the camera tube, an excellent series of uniformly spaced comparison lines is obtained. With only fairly well-timed exposures, there are many more good lines than are needed, so that it is always possible to choose for measures those lying nearest the best star lines.

I have employed throughout Rowland's wave-lengths for the comparison lines; for the vanadium lines, the arc values;[1] and for the iron lines, the arc values for those lines whose arc wave-lengths

[1] Published by Rowland and Harrison in *Astrophysical Journal*, 7, 273, April 1898.

he has published,[1] for the others, the values given in his table of solar wave-lengths.

Rowland's solar wave-lengths have been used for the wave-lengths of the stellar lines. I have, as far as possible, measured single lines, but have also employed a number of composite lines which appear single, and well suited to measurement, on my spectrograms. For the wave-lengths of these composite, or blended, lines, I have, as is customary, used the values resulting from giving to the wave-length of each component of the blend the weight of its intensity given in Rowland's table, and taking the weighted mean. The weakest line ordinarily taken into account is that of "0" intensity, which has generally been given a weight of one-half.

On some of the last Moon and planet plates, I have measured a rather large number of lines, both single and blended, for the purpose of seeing how the velocities from the blended lines compare with those from single lines. To the same end, I have also measured the strong solar lines at $\lambda\lambda$ 4326, 4384, 4405, and 4415. A comparison of the results from single and from blended and from the very strong lines shows that measures on the single lines are not noticeably more accurate than on the blends and heavy lines, and also that the values for the wave-lengths of the blended lines are reliable. Of course, with stars of the advanced solar type of spectrum, the class to which most of the "Standard Velocity Stars" belong, the relative intensities of lines must frequently be different from what they are in the Sun, and therefore the wave-lengths of the blends in such cases must be inaccurate. I have observed, for instance, that the blend $\lambda\,4352.935 \begin{cases} 4352.908\ (4)\ Fe \\ 4352.044\ (1)^{2}\ V \end{cases}$ in certain stars gives a larger positive velocity than the mean value of the other lines. However, similar uncertainties must attach to some of the lines which are single in the Sun. As an example of this kind may be mentioned the line at λ 4468.663, an excellent single in the Sun, of intensity 5, due to

[1] "A New Table of Standard Wave-lengths," *Astronomy and Astrophysics*, **12**, April 1903; and Frost's Scheiner's *Astronomical Spectroscopy*, p. 363.

[2] The vanadium lines are generally stronger in these stars than in the Sun, and in this blend I have given the *V* component weight 1, although its intensity is given as 0 by Rowland. I have used this wave-length for the blend, with Moon and planets, as well as with the stars.

titanium, which appears as a single on the star plates but which, in *a Boötis* for example, gives a too large positive velocity.[1]

I continued to measure certain stellar lines after I knew solar wave-lengths were not entirely applicable and that they were giving spurious velocities. The employment of such lines, however, has only slightly affected the velocity of a plate and they can at any time be excluded or their velocities corrected when the wave-lengths have been more accurately determined. The inclusion of such lines by the different co-operators in their first year's observations would give provisional corrections to their wave-lengths, thus making the lines useful for velocity observations of these and other stars of the same spectral type. I am of the opinion that, after all, one of the most important results of this co-operation in radial velocity observations will be the knowledge gained of the wave-lengths of the star lines.

The plates have been measured with a screw microscope[2] designed especially for measurement of spectrum plates. The screw, which has a pitch of half a millimeter, was examined for errors. Periodic errors were not revealed by the tests, although errors of run were quite apparent, and were of such a character as would be explained by a tapering of the screw from the middle toward the ends. I have not attempted to apply corrections to the measures to take up this error (which accumulates at a rate of about 0.3 μ per revolution), for the reason that its gradual change would practically affect equally the star and near-by comparison line. I do not consider that the measures are appreciably affected by this imperfection of the screw. I have always measured the plate in both positions, violet-right and violet-left, under the microscope, making generally four settings on the star line and two each on the upper and lower part of the comparison line. The best star lines have been measured, regardless of whether or not they existed in the comparison spectrum. The comparison lines lying nearest the measured star lines have been selected, the distance between the star and the comparison line amounting only in exceptional cases to as much as 3 tenth-meters. This close proximity of the spark and the star line practically renders inoperative the errors in run of the micrometer screw.

[1] Frost's and Adams's velocities verify my own as regards the wave-length of this line.

[2] This instrument was made by Gaertner & Co., of Chicago, and is a duplicate of those used by Frost and Adams.

A magnification of 21 diameters has been used in the measurements.

The measures in the two positions of the plate have not been reduced separately, but have been combined and the mean taken before the reduction was begun.

I have adopted the method of reducing each plate independently of every other, by computing for each plate a new Hartmann formula in the simple form

$$\lambda-\lambda_0=\frac{C}{R-R_0},$$

where R denotes the screw reading. The constants R_0, C, and λ_0 of the formula are computed (in the order given) from the observed screw-readings and known wave-lengths of three comparison lines so selected that there is one near each end and the third near the middle of the portion of spectrum measured. By casting away a factor to make the reading on one of the lines zero, and by the use of logarithms, the constants are derived in about eight minutes. The wave-lengths of all star and comparison lines are then computed. The differences between the computed and normal wave-lengths of the numerous comparison lines furnish the necessary corrections for reducing the star wave-lengths to the true dispersion-curve of the plate. I have applied these corrections to the star lines without the use of a curve, making linear interpolations where needed; the mean of the errors of two neighboring comparison lines frequently being employed for the correction to the intervening star line. The differences between these corrected stellar wave-lengths and their normal values are then taken as the velocity displacements for the star lines. These displacements are speedily converted into velocity in the line of sight by a Crelle's table suitably supplied with notes.

The theoretical velocities of the planets and the Moon have been computed from data given in the *American Ephemeris*, by the aid of Professor Campbell's convenient formulæ. In the reduction of the star velocities to the Sun, Schlesinger's line-of-sight constants have been employed for computing the factor V_a due to the Earth's orbital velocity. The other factor, V_d, due to the Earth's diurnal rotation, is read from a table. In the case of the earlier plates the correction for prismatic curvature has been applied to the mean velocity, and appears at the foot of the reduction table. In the other cases it has

been introduced earlier in the reductions and affects the velocities of the individual lines.

Object	Number of Plate	Greenwich M. T.	Velocity			No. of Lines	Quality of Plate
			Obs.	Comp.	Residu'ls O.—C.		
			km	km	km		
Mars..........	L 1868	1905 April 28^d 18^h 42^m	− 8.39	− 7.92	−0.5	21	Good
Mars..........	L 1881	May 18 15 30	− 1.10	− 1.62	+0.5	17	Good
Venus..........	L 1937	July 11 0 21	+13.72	+13.42	+0.3	26	Overexposed
Moon..........	L 1944	13 18 35	+ 1.30	+ 0.52	+0.8	27	Underexposed
Moon..........	L 2013	Aug. 12 19 28	+ 0.53	+ 0.25	+0.3	26	Good
Moon..........	L 2091	Oct. 5 15 40	+ 0.55	+ 0.65	−0.1	24	Excellent
Mars..........	L 2096	6 13 52	+ 9.02	+ 9.16	−0.1	35	Good
Venus..........	L 2113	13 1 15	+ 8.70	+ 8.64	+0.1	36	Excellent

The results from all the planet and Moon plates, made at intervals to test the performance of the spectrograph, are here summarized in a brief table. These check plates cover the whole period during which the "Standard Velocity Stars" have been under observation. The last two of these plates are also printed in detail to show the lines measured and to illustrate the character of the results from the individual lines. The mean value of O.—C. = +0.15 km is doubtless only accidental as it is due to the rather large positive value of one of the less reliable plates. (I consider plates having *V* comparison lines much more reliable than those having the *Mo* lines.) It seems safe to conclude from these tests that the spectrograph has not been affected by appreciable systematic errors during the period covered by this series of velocity observations.

In the following pages are given in tabulated form the detailed reductions of all the plates of the "Standard Velocity Stars." The date of the plate is given in Greenwich Mean Time, above the table. The hour angle is also added. Just over the head of the table is a note descriptive of the quality of the plate. The first column of the table contains the wave-length of the star line and the second column, the velocity deduced for the line, given to the tenth of a kilometer per second. At the foot of these columns is given the mean of the velocities from the several lines, followed by V_a and V_d, the reductions to the Sun; and next the value of the star's radial velocity. Below these will be found the mean error $\epsilon = \pm\sqrt{\frac{\Sigma v^2}{n-1}}$ of the determination of the velocity from a single line, and the mean

error $\epsilon_0 = \pm\sqrt{\frac{\Sigma v^2}{m(n-1)}}$ of the final velocity of the star deduced from the plate.

The stars are arranged in the order of their right ascensions and the plates of each are given in chronological order.

MARS—L 2096

1905 Oct. 6^d 13^h 52^m
Hour angle W 1^h 27^m
Planet spectrum good; comparison lines (V, Fe) good.

Line λ (Solar)	Velocity
4274.911	+11.7km
93.241	11.7
94.273	8.7
4307.938	6.9
14.321	8.2
15.178	9.1
18.817	9.7
25.951	9.4
37.216	6.6
40.634	10.7
52.006	9.3
52.935	8.7
59.784	9.1
76.107	5.8
78.419	11.9
79.396	5.5
80.883	12.3
83.720	8.5
95.286	7.4
4404.951	7.1
06.810	6.7
07.851	7.2
08.549	7.1
15.244	10.2
27.420	9.1
35.184	7.5
42.510	10.3
43.976	13.0
47.892	10.0
56.030	10.7
59.304	11.7
68.663	8.3
76.214	8.5
82.376	11.0
94.738	6.4

Mean +9.02km
Computed vel. +9.16

O.—C. −0.1km

No. of Martian lines 35
No. of comp. lines 32

VENUS—L 2113

1905 Oct. 13^d 1^h 15^m
Hour angle E 4^h 15^m
Planet spectrum excellent; comparison lines (V, Fe) excellent.

Line λ (Solar)	Velocity
4238.970	+9.1km
39.975	6.7
45.455	6.3
47.580	11.2
50.287	8.2
50.959	7.2
54.505	5.5
71.934	7.6
74.911	8.4
93.241	7.7
94.273	7.7
4306.938	6.8
14.321	10.2
15.178	7.4
18.817	9.6
25.951	7.2
40.634	8.4
52.006	9.1
52.935	8.9
59.784	7.0
83.720	7.2
95.286	8.3
4404.951	7.0
07.851	6.4
08.549	10.8
27.420	9.8
35.184	9.9
42.510	8.0
43.976	10.8
47.892	10.3
56.030	11.2
59.304	9.8
68.663	9.9
76.214	11.1
82.376	11.0
4528.798	11.3

Mean +8.70km
Computed vel. +8.64

O.—C.= +0.1km

No. of *Venus* lines 36
No. of comp. lines 30

α ARIETIS—L 2067

1905 Sept. 12ᵈ 20ʰ 48ᵐ
Hour angle E 1ʰ 20ᵐ
Star spectrum fair; comparison lines (V, Fe) excellent.

Line λ (Solar)	Velocity
4315.178	−35.3km
18.817	33.5
28.080	35.0
37.216	35.2
40.634	33.7
52.006	36.3
52.935	33.6
59.784	37.7
76.107	38.4
95.286	37.7
4407.851	39.4
08.549	33.7
27.420	33.5
28.711	38.7
42.510	35.9
47.892	35.0
59.304	32.3
68.663	34.0
76.214	35.7
91.620	34.6
4505.003	31.0
28.798	35.5

Mean −35.26km
V_a +20.80
V_d + 0.12
Red. to Sun +20.92

Rad. vel. −14.3km

No. of star lines. 22
No. of comp. lines 25
ε ±2.05
ϵ_0 ±0.43

α ARIETIS—L 2085

1905 Oct. 2ᵈ 20ʰ 8ᵐ
Hour angle E 0ʰ 30ᵐ
Star spectrum good; comparison lines (V, Fe) good.

Line λ (Solar)	Velocity
4315.178	−29.7km
18.817	24.9
28.080	25.9
40.634	27.3
41.530	26.9
52.006	30.6
52.935	27.2
59.784	30.9
76.107	28.5
95.286	28.0
4406.810	30.0
4407.851	−27.3km
08.549	24.1
27.420	25.5
28.711	26.4
41.881	29.8
42.510	23.6
47.892	24.8
56.030	26.5
60.460	23.5
66.701	25.3
68.663	25.8
76.214	25.6
82.376	25.0
94.738	27.5
97.046	26.3
4501.422	30.9
28.798	24.8

Mean −26.88km
V_a +12.81
V_d + 0.05
Red. to Sun +12.86

Rad. vel. −14.0km

No. of star lines 28
No. of comp. lines 27
ε ±2.21
ϵ_0 ±0.42

α ARIETIS—L 2094

1905 Oct. 5ᵈ 18ʰ 54ᵐ
Hour angle E 1ʰ 40ᵐ
Star spectrum good; comparision lines (V, Fe) good.

Line λ (Solar)	Velocity
4318.817	−25.2km
28.080	27.7
39.731	28.0
40.634	27.1
52.006	26.4
52.935	24.0
59.784	28.7
76.107	28.2
95.286	28.2
99.903	28.4
4406.810	27.2
07.851	28.9
27.420	23.4
28.711	28.2
35.851	28.2
41.881	26.8
43.976	22.0
47.892	24.9
56.030	22.6
68.663	25.4
76.214	25.8
82.376	24.5
82.904	22.3
4490.950	−27.6km
97.046	24.9
97.842	23.5

Mean −26.08km
V_a +11.47
V_d + 0.15
Red. to Sun +11.62

Rad. vel. −14.5km

No. of star lines 26
No. of comp. lines 27
ε ±2.17
ϵ_0 ±0.43

α PERSEI—L 2049

1905 August 30ᵈ 23ʰ 6ᵐ
Hour angle E 1ʰ 0ᵐ
Star spectrum good; comparison lines (Fe, V) excellent

Line λ (Solar)	Velocity
4308.023	−26.0km
13.034	29.0
37.216	25.4
59.784	22.3
76.107	27.4
83.720	30.8
94.225	27.5
95.201	26.1
4404.927	28.0
16.985	29.9
27.420	23.6
43.976	26.0
47.892	25.2
59.301	25.5
66.727	28.0
68.663	28.9
76.214	29.9
82.376	24.3
94.738	30.7
4501.448	26.2
08.455	23.9
15.508	26.4
28.798	27.3

Mean −26.89km
Curve corr. − 0.50
V_a +25.29
V_d + 0.06
Red. to Sun +25.35

Rad. vel. − 2.0km

No. of star lines 23
No. of comp. lines 19
ε ±2.10
ϵ_0 ±0.40

α PERSEI—L 2068

1905 Sept. 12^d 21^h 59^m
Hour angle E 1^h 20^m
Star spectrum over-exposed; comparison lines (V, Fe) good.

Line λ (Solar)	Velocity
4294.273	−23.1km
4300.211	21.6
03.419	26.0
05.871	28.9
08.023	24.0
13.034	27.4
15.178	23.0
25.939	23.3
40.634	24.0
52.006	28.1
83.720	28.9
91.146	24.8
95.201	26.1
4404.927	28.8
16.985	27.3
27.420	22.9
59.301	26.3
76.214	25.8
81.400	31.3
91.570	29.6
4508.455	26.9
15.508	26.2
28.798	27.8

Mean −26.18km
V_a +24.04
V_d + 0.08
Red. to Sun +24.12

Rad. vel. − 2.1km

No. of stars line 23
No. of comp. lines 20
ϵ ±2.53
ϵ_0 ±0.53

α PERSEI—L 2079

1905 Sept. 25^d 20^h 40^m
Hour angle E 1^h 35^m
Star spectrum good; comparison lines (V, Fe) good.

Line λ (Solar)	Velocity
4294.273	−25.2km
4300.211	23.0
08.023	26.3
13.034	28.7
15.178	23.2
25.939	24.8
40.634	24.0
52.006	29.2
52.908	22.9
83.720	25.9
94.225	23.1
4395.201	−24.6km
96.008	22.9
4404.927	24.3
16.985	24.0
43.976	22.8
50.654	23.4
59.301	21.4
66.727	23.8
68.663	24.8
91.570	25.2
94.738	27.2
4501.448	21.4
08.455	23.0
15.508	24.5
20.397	21.5
28.798	24.1
34.139	18.7
49.767	23.8
54.211	25.3

Mean −24.10km
V_a +21.59
V_d + 0.10
Red. to Sun +21.69

Rad. vel. − 2.4km

No. of star lines 30
No. of comp. lines 28
ϵ ±2.12
ϵ_0 ±0.39

α PERSEI—L 2100

1905 Oct. 7^d 22^h 53^m
Hour angle W 1^h 10^m
Star spectrum very good; comparison lines (V, Fe) good

Line λ (Solar)	Velocity
4294.273	−21.1km
4308.023	17.9
13.034	21.4
14.321	20.0
15.178	20.6
25.183	21.4
25.939	20.1
38.084	25.3
40.634	22.9
52.006	24.1
52.908	19.9
59.784	15.2
76.107	23.0
83.720	23.1
94.225	20.5
95.201	20.5
4404.927	22.0
16.985	21.3
17.884	19.8
43.976	23.2
50.654	21.2
59.301	20.3
4468.663	−22.6km
69.545	23.4
76.214	21.9
81.400	20.1
82.376	19.4
89.351	20.9
91.570	19.5
94.738	23.6
97.023	18.0
4501.448	21.9
08.455	19.4
15.508	20.9
20.397	22.4
28.798	22.4

Mean −21.14km
V_a +18.32
V_d − 0.07
Red. to Sun +18.25

Rad. vel. − 2.9km

No. of star lines 36
No. of comp. lines 28
ϵ ±1.94
ϵ_0 ±0.32

α PERSEI—L 2124

1905 Oct. 27^d 22^h 7^m
Hour angle W 1^h 47^m
Star spectrum rather strong; comparison lines (V, Fe) good.

Line λ (Solar)	Velocity
4308.023	−12.0km
13.034	12.5
14.321	11.5
25.939	13.7
40.634	14.9
52.908	11.6
76.107	13.1
83.720	15.4
95.201	15.0
4404.927	15.8
16.985	16.4
43.976	13.9
47.892	15.4
50.654	13.6
59.301	15.5
76.214	17.4
4501.448	15.7
28.798	15.9

Mean −14.40km
V_a +11.18
V_d − 0.11
Red. to Sun +11.07

Rad. vel. − 3.3km

No. of star lines 18
No. of comp. lines 18
ϵ ±1.74
ϵ_0 ±0.41

β LEPORIS—L 2087

1905 Oct. 2^d 23^h 56^m
Hour angle E 0^h 8^m
Star spectrum good; comparison lines (*V*, *Fe*) good.

Line λ (Solar)	Velocity
4315.178	-33.6^{km}
25.951	29.7
28.080	30.4
37.216	32.3
40.634	30.8
41.530	33.9
52.006	32.4
52.935	32.5
59.784	34.7
76.107	32.6
83.720	35.0
91.146	35.0
4404.951	30.8
06.810	32.4
07.851	32.8
15.244	33.5
27.420	34.3
42.510	35.2
47.892	30.0
56.030	34.7
59.304	32.5
60.460	31.3
66.701	30.3
68.663	33.7
76.214	33.6
82.376	33.0
85.846	32.9
94.738	34.0
4500.480	32.7
01.422	32.5
15.475	30.5
28.798	31.8

Mean -32.67^{km}
V_a $+19.84$
V_d $+0.01$
Red. to Sun $+19.85$

Rad. vel. -12.8^{km}

No. of star lines 32
No. of comp. lines 30
ϵ ± 1.57
ϵ_0 ± 0.28

β LEPORIS—L 2111

1905 Oct. 12^d 23^h 20^m
Hour angle E 0^h 6^m
Star spectrum somewhat weak; comparison lines (*Fe*, *V*) good.

Line λ (Solar)	Velocity
4314.321	-30.3^{km}
25.951	32.9
4331.762	-30.7^{km}
40.634	31.0
41.530	32.1
52.935	32.2
59.784	33.0
79.396	33.9
83.720	33.9
4404.951	32.6
06.810	31.7
07.851	31.4
08.549	33.3
27.420	32.0
35.184	28.4
43.976	29.4
47.892	30.1
59.304	32.8
60.460	33.2
68.663	31.5
76.214	30.0
94.738	30.0
4501.422	30.2
08.455	29.8
15.475	30.7
28.798	28.8

Mean -31.38^{km}
V_a $+18.22$
V_d $+0.01$
Red. to Sun $+18.23$

Rad. vel. -13.2^{km}

No. of star lines 26
No. of comp. lines 25
ϵ ± 1.56
ϵ_0 ± 0.30

β LEPORIS—L 2125

1905 Oct. 27^d 23^h 17^m
Hour angle W 0^h 47^m
Star spectrum fair; comparison lines (*Fe*, *V*) good.

Line λ (Solar)	Velocity
4315.178	-27.1^{km}
25.951	26.7
28.080	29.1
40.634	24.9
52.006	29.6
52.935	29.9
59.784	28.4
79.396	31.4
83.720	31.3
95.286	28.7
4404.951	28.7
06.810	32.9
08.549	28.8
25.608	24.6
27.420	26.6
42.510	27.0
47.892	29.0
4459.304	-25.2^{km}
68.663	28.9
76.214	23.6
4501.422	24.9
08.455	28.1
22.853	23.6
28.798	24.3

Mean -27.64^{km}
V_a $+14.75$
V_d -0.07
Red. to Sun $+14.68$

Rad. vel. -13.0^{km}

No. of star lines 24
No. of comp. lines 24
ϵ ± 2.56
ϵ_0 ± 0.52

β GEMINORUM—L 1833

1905 April 7^d 17^h 0^m
Hour angle W 2^h 58^m
Star spectrum fair; comparison lines (*Ti*, *Cr*) weak.

Line λ (Solar)	Velocity
4274.911	$+36.9^{km}$
93.241	35.5
94.273	30.5
4306.938	32.6
14.321	37.5
15.178	30.9
18.817	35.9
28.080	33.3
39.731	32.7
40.634	35.7
49.107	37.7
52.006	34.5
52.935	35.1
59.784	31.9
99.903	31.0
4406.810	31.0
07.851	34.6
08.549	32.3
27.420	30.8
42.510	33.0
57.656	33.7
59.304	32.2

Mean $+33.60^{km}$
Curv. cor. -0.60
V_a -29.40
V_d -0.23
Red. to Sun -29.63

Rad. vel. $+3.4^{km}$

No. of star lines 22
No. of comp. lines 13
ϵ ± 2.13
ϵ_0 ± 0.45

β GEMINORUM—L 2101

1905 Oct. $7^{d}\ 23^{h}\ 39^{m}$
Hour angle E $2^{h}\ 22^{m}$
Star spectrum fair only; comparison lines (*V*, *Fe*) good.

Line λ (Solar)	Velocity
4293.241	-27.8^{km}
4314.321	21.6
15.178	28.2
18.817	23.1
25.951	26.6
28.080	27.7
37.216	27.7
40.634	29.6
52.006	28.4
52.935	26.8
59.784	27.4
83.720	27.7
95.286	27.4
99.903	29.9
4406.810	25.5
08.549	25.3
15.244	26.0
27.420	28.0
42.510	25.0
47.892	26.7
59.304	23.6
68.663	25.2
76.214	27.6
82.376	25.6
85.846	23.8
4528.798	25.7

Mean -26.46^{km}
V_a $+29.41$
V_d $+0.20$
Red. to Sun $+29.61$

Rad. vel. $+3.2^{km}$

No. of star lines 26
No. of comp. lines 22
ϵ ± 1.98
ϵ_0 ± 0.39

β GEMINORUM—L 2117

1905 Oct. $15^{d}\ 1^{h}\ 5^{m}$
Hour angle E $0^{h}\ 20^{m}$
Star spectrum fair only; comparison lines (*V*, *Fe*) a trifle weak.

Line λ (Solar)	Velocity
4314.321	-27.2^{km}
15.178	29.8
18.817	27.5
4328.080	-28.9^{km}
52.935	29.0
59.784	29.9
95.286	25.9
4407.851	26.2
08.549	23.0
27.420	25.5
28.711	27.8
47.892	23.3
56.030	23.2
57.656	26.4
68.663	24.7
76.214	26.5
82.376	26.2
94.738	24.5
4501.422	25.6
28.798	25.0

Mean -26.30^{km}
V_a $+29.66$
V_d $+0.03$
Red. to Sun $+29.69$

Rad. vel. -3.4^{km}

No. of star lines 20
No. of comp. lines 20
ϵ ± 2.08
ϵ_0 ± 0.46

α BOÖTIS—L 1850

1905 April $14^{d}\ 20^{h}\ 15^{m}$
Hour angle $0^{h}\ 0^{m}$
Star spectrum fair only; comparison lines (*Ti*, *Cr*) weak.

Line λ (Solar)	Velocity
4293.241	-5.5^{km}
4318.817	3.3
52.006	5.2
52.935	1.2
59.784	4.4
76.107	5.6
79.396	5.5
94.161	6.0
95.286	5.5
99.903	4.8
4400.615	3.5
06.810	6.5
08.549	2.5
27.420	4.3
42.510	4.4
45.641	2.0
47.892	3.4
57.656	7.4
68.663	6.2

Mean -4.59^{km}
Curv. corr. -0.50
V_a -0.37
V_d ± 0.00
Red. to Sun -0.37

Rad. vel. -5.5^{km}

No. of star lines 19
No. of comp. lines 15
ϵ ± 1.69
ϵ_0 ± 0.37

α BOÖTIS—L 2011

1905 Aug. $12^{d}\ 16^{h}\ 6^{m}$
Hour angle W $3^{h}\ 50^{m}$
Star spectrum excellent; comparison lines (*Fe*, *V*) good.

Line λ (Solar)	Velocity
4344.597	$+19.6^{km}$
52.935	19.3
59.784	17.2
69.933	20.0
79.396	17.5
90.149	16.1
91.146	17.9
4406.810	19.3
07.851	17.5
18.499	21.0
27.420	20.2
28.711	17.5
35.851	17.6
41.881	16.9
42.510	19.6
47.892	21.0
56.030	21.2
57.656	20.0
59.304	20.0
60.460	18.3
68.663	19.9
76.214	19.5
82.376	21.1
97.046	20.6
4501.422	20.8
28.798	20.7
29.774	19.7
34.953	20.6

Mean $+19.30^{km}$
Curv. corr. -0.55
V_a -22.40
V_d -0.30
Red. to Sun -22.70

Rad. vel. -4.0^{km}

No. of star lines 28
No. of comp. lines 29
ϵ ± 1.45
ϵ_0 ± 0.28

α BOÖTIS—L 2016

1905 Aug. 15^d 16^h 8^m
Hour angle W 4^h 10^m
Star spectrum good; comparision lines (V, Fe) good.

Line λ (Solar)	Velocity
4352.935	+18.8km
59.784	15.0
79.396	15.6
89.413	15.7
4406.810	16.3
07.851	15.1
18.499	19.2
27.420	19.9
28.711	17.9
35.851	14.0
41.881	14.9
42.510	18.1
47.892	19.9
57.656	18.1
60.460	19.1
61.818	19.6
66.701	20.4
68.663	19.7
76.214	18.6
82.904	19.7
94.738	19.9
97.046	21.4
4501.422	18.7
28.798	20.7
34.953	18.6

Mean	+18.20km
Curv. corr.	− 0.45
V_a −21.79	
V_d − 0.32	
Red. to Sun	−22.11
Rad. vel.	− 4.4km
No. of star lines	25
No. of comp. lines	22
ε ±2.08	
ϵ_0 ±0.42	

α BOÖTIS—L 2043

1905 Aug. 29^d 15^h 34^m
Hour angle W 4^h 30^m
Star spectrum excellent; comparison spectrum lines (V, Fe) excellent

Line λ (Solar)	Velocity
4352.006	+13.6km
52.935	16.9
59.784	14.2
79.396	12.1
89.413	15.0
4390.149	+14.0km
99.903	13.8
4406.810	12.5
07.851	12.3
15.722	12.9
27.420	16.0
28.711	13.3
41.881	12.3
42.510	13.4
47.892	15.2
57.656	13.9
59.304	14.7
60.460	15.5
68.663	16.0
76.214	14.3
82.376	15.9
94.738	12.3
97.046	14.6

Mean	+14.12km
Curv. corr.	− 0.55
V_a −18.22	
V_d − 0.33	
Red. to Sun	−18.55
Rad. vel.	− 5.0km
No. of star lines	23
No. of comp. lines	23
ε ±1.26	
ϵ_0 ±0.28	

α BOÖTIS—L 2053

1905 Aug. 31^d 15^h 31^m
Hour angle W 4^h 35^m
Star spectrum excellent; comparison lines (Fe, V) good.

Line λ (Solar)	Velocity
4337.216	+16.1km
48.045	13.8
52.935	16.3
59.784	13.3
69.933	14.2
79.396	11.1
89.413	14.8
91.146	11.3
4406.810	12.9
07.851	12.6
27.420	15.0
28.711	11.4
42.510	13.5
47.892	15.4
56.030	15.0
59.304	15.5
60.460	14.4
68.663	15.3
76.214	15.6
82.376	14.0

Mean	+14.07km
Curv. corr.	− 0.60
V_a −17.62	
V_d − 0.33	
Red. to Sun	−17.95
Rad. vel.	− 4.5km
No. of star lines	20
No. of comp. lines	20
ε ±1.60	
ϵ_0 ±0.36	

β OPHIUCHI—L 1947

1905 July 14^d 19^h 10^m
Hour angle W 1^h 45^m
Star spectrum fair; comparison lines (Mo, Fe) fair.

Line λ (Solar)	Velocity
4352.006	+0.3km
52.935	4.0
59.784	2.3
79.396	−1.4
4406.810	1.5
07.851	+1.7
08.549	1.8
27.420	2.1
38.510	−1.1
42.510	+1.8
47.892	2.4
57.656	4.6
59.304	2.6
60.460	3.4
68.663	− 0.5
76.214	0.5
90.950	1.3
97.046	+1.3
4528.798	0.5
34.953	−1.9

Mean	+1.03km
Curv. corr.	−0.55
V_a −12.25	
V_d − 0.16	
Red. to Sun	−12.41
Rad. vel.	−11.9km
No. of star lines	20
No. of comp. lines	21
ε ±1.95	
ϵ_0 ±0.44	

β OPHIUCHI—L 2017

1905 Aug. 15^d 17^h 50^m
Hour angle W 2^h 30^m
Star spectrum good; comparison lines (*Fe*, *V*) strong.

Line λ (Solar)	Velocity
4328.080	+15.0^{km}
39.731	10.8
49.107	14.2
52.006	10.5
52.935	13.1
59.784	11.9
79.396	10.1
89.413	12.6
99.903	9.4
4406.810	11.4
07.851	13.0
08.549	13.2
27.420	13.5
42.510	10.5
47.892	8.1
57.656	13.9
59.304	14.0
60.460	11.3
68.663	14.8
76.214	12.7
90.950	11.0

Mean	+12.14^{km}
Curv. corr.	− 0.42
V_a −22.33	
V_d − 0.23	
Red. to Sun	−22.56
Rad. vel.	−10.8^{km}
No. of star lines	21
No. of comp. lines	23
ε ±1.71	
$ε_0$ ±0.37	

β OPHIUCHI—L 2058

1905 Sept. 8^d 16^h 32^m
Hour angle W 2^h 35^m
Star spectrum fair; comparison lines (*Fe*, *V*) good.

Line λ (Solar)	Velocity
4328.080	+14.8^{km}
31.762	12.7
52.006	12.8
52.935	15.4
59.784	13.8
69.868	18.4
79.396	12.4
4395.286	−13.9^{km}
4406.810	16.9
08.549	13.6
15.244	18.1
27.420	16.0
28.711	11.9
42.510	16.5
47.892	14.3
59.304	18.4
60.460	18.0
69.549	19.4
76.214	14.6
82.376	18.1
94.738	12.7
4522.853	15.3
28.798	14.4

Mean	+15.31^{km}
Curv. corr.	− 0.45
V_a −25.89	
V_d − 0.22	
Red. to Sun	−26.11
Rad. vel.	−11.3^{km}
No. of star lines	23
No. of comp. lines	23
ε ±2.32	
$ε_0$ ±0.48	

γ AQUILAE—L 1921

1905 July 5^d 21^h 5^m
Hour angle W 0^h 50^m
Star spectrum good; comparison lines (*Ti*, *Mo*, *Cr*, *Fe*) overexposed.

Line λ (Solar)	Velocity
4321.931	−13.4^{km}
28.080	4.5
31.762	7.7
34.967	6.2
39.731	11.0
52.006	9.6
52.935	6.3
59.784	8.4
64.273	9.8
76.107	13.0
79.396	11.2
95.286	9.0
4400.615	7.7
27.420	7.3
42.510	9.8
47.892	10.1
59.304	9.3
68.663	8.1
75.026	7.1
76.214	10.6

Mean	−9.00^{km}
Curv. corr.	−0.50
V_a +6.89	
V_d −0.08	
Red. to Sun	+6.81
Rad. vel.	−2.7^{km}
No. of star lines	20
No. of comp. lines	14
ε ±2.30	
$ε_0$ ±0.51	

γ AQUILAE—L 1926

1905 July 7^d 20^h 25^m
Hour angle W 0^h 20^m
Star spectrum good; comparison lines (*Mo*, *Fe*) weak.

Line λ (Solar)	Velocity
4328.080	−4.9^{km}
31.762	6.9
39.731	7.1
52.935	6.6
59.784	7.4
69.933	7.2
79.396	9.7
95.286	9.1
4407.851	12.4
27.420	3.9
42.510	9.9
47.892	8.8
57.656	10.5
59.304	7.1
68.663	5.9

Mean	−7.83^{km}
Curv. corr.	−0.50
V_a +6.08	
V_d −0.03	
Red. to Sun	+6.05
Rad. vel.	−2.3^{km}
No. of star lines	15
No. of comp. lines	18
ε ±2.23	
$ε_0$ ±0.57	

γ *AQUILAE*—L 1952

1905 July 15[d] 19[h] 50[m]
Hour angle W 0[h] 15[m]
Star spectrum fair; comparison lines (*Mo. Fe*) fair.

Line λ (Solar)	Velocity
4328.080	−2.4km
49.107	1.8
52.935	2.2
59.784	2.4
62.262	6.9
76.107	2.7
79.396	3.7
4400.615	2.7
06.810	4.6
07.851	5.2
27.420	2.2
42.510	4.9
47.892	6.5
56.030	6.7
57.656	6.6
60.460	7.1
68.663	0.7
72.956	4.4

Mean −4.10km
V_a +2.77
V_d −0.02
Red. to Sun +2.75

Rad. vel. −1.3km

No. of star lines 18
No. of comp. lines 13
ε ±2.06
ϵ_0 ±0.49

ε *PEGASI*—L 1948

1905 July 14[d] 21[h] 18[m]
Hour angle E 0[h] 24[m]
Star spectrum good; comparison lines (*Fe, Mo*) good

Line λ (Solar)	Velocity
4331.762	−12.6km
52.935	7.9
59.784	6.1
76.107	11.4
79.396	10.9
4407.851	9.7
33.390	9.6
41.881	15.0
42.510	11.5
45.641	10.6
56.030	14.0
57.656	10.2
59.304	8.3
4468.663	−6.7km
76.214	11.3
82.376	9.1
82.904	10.3
4501.422	9.5
05.003	8.7
28.798	10.7
29.774	10.0

Mean −10.20km
Curv. corr. − 0.50
V_a +16.77
V_d + 0.04
Red. to Sun +16.81

Rad. vel. + 6.1km

No. of star lines 21
No. of comp. lines 17
ε ±2.18
ϵ_0 ±0.47

ε *PEGASI*—L 2007

1905 Aug. 10[d] 20[h] 42[m]
Hour angle W 0[h] 50[m]
Star spectrum very good; comparison lines (*Ti, Fe*) good.

Line λ (Solar)	Velocity
4318.817	+4.6km
28.080	1.2
31.762	4.2
47.403	1.9
49.107	−0.6
52.935	+2.1
59.784	2.5
76.107	−2.9
79.396	1.9
89.413	1.2
91.146	2.9
94.161	+1.1
95.286	0.4
4406.810	−1.4
07.851	1.4
27.420	+0.4
41.881	−1.5
42.510	2.0
45.641	+2.4
47.892	0.9
57.656	−2.8
59.304	+0.9
60.460	−1.7
68.663	+1.4
76.214	0.4
85.846	2.5
97.046	−1.6
4500.480	+3.4
05.003	1.8
12.063	0.1
4512.906	−0.8km
14.513	0.9
15.475	3.0
28.798	−1.7

Mean +0.39km
Curv. corr. −0.45
V_a +5.65
V_d −0.08
Red. to Sun +5.57

Rad. vel. +5.5km

No. of star lines 34
No. of comp. lines 25
ε ±2.01
ϵ_0 ±0.34

ε *PEGASI*—L 2054

1905 Sept. 6[d] 18[h] 48[m]
Hour angle W 0[h] 45[m]
Star spectrum good; comparison lines (*V, Fe*) fair.

Line λ (Solar)	Velocity
4331.762	+15.5km
49.107	12.5
52.935	16.1
59.784	14.2
76.107	11.2
79.396	11.9
89.413	14.0
91.146	11.6
95.286	14.7
98.272	14.1
4427.420	16.1
42.510	15.8
47.892	11.2
56.030	15.8
59.304	16.8
60.460	11.7
68.663	16.7
76.214	12.2
82.376	13.9
94.738	12.5
4515.475	16.6
28.798	14.9

Mean +14.10km
V_a −6.74
V_d −0.08
Red. to Sun −6.82

Rad. vel. +7.3km

No. of star lines 22
No. of comp. lines 23
ε ±1.79
ϵ_0 ±0.39

ε *PEGASI*—L 2080

1905 Sept. 27^d 17^h 28^m
Hour angle W 0^h 48^m
Star spectrum good; comparison lines (*Fe*, *V*) somewhat strong.

Line λ (Solar)	Velocity
4328.080	+18.7^km
49.107	19.3
52.935	23.0
56.110	19.9
59.784	18.4
76.107	19.0
89.413	21.2
90.149	19.8
95.286	18.0
4406.810	19.8
07.851	22.1
27.420	24.9
28.711	19.3
35.851	20.8
41.881	20.0
42.510	23.4
45.641	23.3
47.892	22.0
57.656	23.7
59.304	24.2
68.663	26.2
76.214	21.7
82.376	25.0
94.738	16.4
97.046	23.6

Mean +21.35^km
V_a −15.71
V_d − 0.08
Red. to Sun −15.79

Rad. vel. + 5.6^km

No. of star lines 25
No. of comp. lines 25
ε ±2.21
ϵ_0 ±0.44

γ *PISCIUM*—L 2081

1905 Sept. 27^d 19^h 15^m
Hour angle W 1^h 25^m
Star spectrum fair; comparison lines (*V*, *Fe*) good.

Line λ (Solar)	Velocity
4314.321	− 4.0^km
15.178	8.4
25.951	3.7
28.080	3.0
37.216	5.4
40.634	5.7
41.530	0.7
52.006	7.5
52.935	6.0
4359.784	−7.8^km
76.107	6.8
79.396	5.3
83.720	5.5
95.286	8.1
4406.810	2.3
08.549	3.1
15.244	2.5
27.420	4.3
41.881	1.5
42.510	1.0
45.641	0.2
47.892	4.0
57.656	3.1
59.304	1.7
68.663	5.0
76.214	3.0
82.376	1.4
88.363	0.0
94.738	4.9
97.046	0.0

Mean −3.86^km
V_a −7.79
V_d −0.13
Red. to Sun − 7.92

Rad. vel. −11.8^km

No. of star lines 30
No. of comp. lines 23
ε ±2.56
ϵ_0 ±0.45

γ *PISCIUM*—L 2122

1905 Oct. 27^d 18^h 22^m
Hour angle W 2^h 10^m
Star spectrum fair; comparison lines(*V*, *Fe*) good.

Line λ (Solar)	Velocity
4294.273	+15.0^km
4315.178	12.0
28.080	13.4
40.634	11.0
52.006	13.9
52.935	14.4
59.784	9.3
78.419	9.2
79.396	7.3
83.720	9.3
95.286	7.0
4404.951	6.3
06.810	12.0
07.851	8.0
08.549	9.0
15.244	13.9
27.420	10.9
42.510	10.0
68.663	8.4
76.214	7.2
94.738	5.4
4501.422	−9.4^km
08.455	10.1
28.798	11.9

Mean +10.19^km
V_a −20.99
V_d − 0.20
Red. to Sun −21.19

Rad. vel. −1.0^km

No. of star lines 24
No. of comp. lines 24
ε ±2.60
ϵ_0 ±0.53

γ *PISCIUM*—L 2129

1905 Nov. 2^d 17^h 0^m
Hour angle W 1^h 20^m
Star spectrum fair; comparison lines (*V*, *Fe*) good.

Line λ (Solar)	Velocity
4293.241	+11.6^km
94.273	10.6
4306.938	11.4
15.178	11.6
25.951	12.3
31.762	10.0
37.216	13.8
40.634	12.3
52.006	9.0
52.935	14.3
59.784	8.3
77.407	12.3
95.286	10.0
4404.951	9.8
08.549	12.3
27.420	11.2
41.881	11.6
42.510	12.9
47.892	13.7
57.656	12.4
59.304	12.0
60.460	12.9
76.214	15.4
82.376	15.4
4501.422	12.6
28.798	15.5

Mean +12.12^km
V_a −23.08
V_d − 0.12
Red. to Sun −23.20

Rad. vel. −11.1^km

No. of star lines 26
No. of comp. lines 24
ε ±1.88
ϵ_0 ±0.37

γ CEPHEI—L 2109

1905 Oct. 12^{d} 20^{h} 45^{m}
Hour angle W 3^{h} 5^{m}
Star spectrum fair; comparison lines (*V*, *Fe*) good.

Line λ (Solar)	Velocity
4293.241	−50.8^{km}
94.273	49.4
4315.178	52.4
18.817	49.8
28.080	48.2
37.216	50.9
39.731	53.0
52.006	49.1
52.935	47.8
59.784	51.5
77.407	44.8
95.286	50.2
4406.810	48.3
07.851	51.8
08.549	49.0
27.420	46.4
28.711	49.8
42.510	47.7
43.976	46.5
47.892	46.3
57.656	43.3
59.304	48.0
68.663	51.6
76.214	45.9
82.376	44.9
97.046	44.5
4528.798	47.7

Mean −48.50^{km}
V_a +7.96
V_d −0.06
Red. to Sun + 7.90

Rad. vel. −40.6^{km}

No. of star lines 27
No. of comp. lines 28
ϵ ±2.60
ϵ_0 ±0.50

γ CEPHEI—L 2123

1905 Oct. 27^{d} 20^{h} 45^{m}
Hour angle W 4^{h} 5^{m}
Star spectrum fair; comparison lines (*V*, *Fe*) good.

Line λ (Solar)	Velocity
4315.178	−45.9^{km}
28.080	44.5
40.634	44.4
52.935	46.0
59.784	47.4
79.396	49.5
95.286	46.1
4408.549	49.2
27.420	46.7
28.711	49.3
47.892	47.1
59.304	45.1
68.663	47.2
76.214	47.7
94.738	47.6
96.046	49.8
4501.422	49.9
28.798	47.9

Mean −47.30^{km}
V_a +5.15
V_d −0.08
Red. to Sun +5.07

Rad. vel. −42.2^{km}

No. of star lines 18
No. of comp. lines 19
ϵ ±2.00
ϵ_0 ±0.47

γ CEPHEI—L 2130

1905 Nov. 2^{d} 19^{h} 50^{m}
Hour angle W 3^{h} 35^{m}
Star spectrum weak and unsymmetrical; comparison lines (*V*, *Fe*) good.

Line λ (Solar)	Velocity
4315.178	−47.9^{km}
28.080	48.2
52.006	49.8
52.935	46.9
59.784	48.3
4408.549	49.6
09.328	44.6
15.244	43.2
27.420	46.3
28.711	48.5
57.656	49.6
59.304	47.8
66.701	42.9
75.026	47.2
76.214	46.6
82.376	42.0
4528.798	47.6

Mean −46.88^{km}
V_a +3.91
V_d −0.07
Red. to Sun + 3.84

Rad. vel. −43.0^{km}

No. of star lines 17
No. of comp. lines 18
ϵ ±2.39
ϵ_0 ±0.58

The resulting velocities for the different plates tabulated above are here collected into a table. The first part of this table contains the values of the velocity deduced from each star plate, followed by their unweighted mean, which is given as the velocity of the star. In the second part of the table are given for comparison the results by other observers of the same star.

It will be noticed that I have in general measured many more lines than is common in such observations. This has increased the accuracy of my velocities by decreasing the effect of accidental errors of measurement, which arise from the somewhat inferior definition

in the spectrograms. Although fairly accurate results are obtained in this way, the extra labor in the measurement and reduction is quite considerable. The spectrograph is soon to be remodeled so as to improve the definition and to render accurate velocity observations possible with less labor.

α *ARIETIS*

Slipher		Other Observers			
Date, 1905	Velocity	Observer	Velocity	No. of Plates	Range
Sept. 12^{d} 21^{h}...	-14.3^{km}	Frost[1]...........	-13.5^{km}	3	0.8^{km}
Oct. 2 20 ...	−14.0	Adams[1]..........	−13.9		0.7
Oct. 5 19 ...	−14.5	Adams[2]..........	−13.7	1	...
		Campbell[3].......	−14.1	4	0.6
Mean......	−14.3	Newall[4]..........	−14.3	3	2.8
		Lord and Maag[5]..	−12.4[7]	5	1.8
		Lord[3]...........	−14.0	2	2.7
		Newall[6]	−16.4	8	6.3

α *PERSEI*

Slipher		Other Observers			
Date, 1905	Velocity	Observer	Velocity	No. of Plates	Range
Aug. 30^{d} 23^{h}...	-2.0^{km}	Frost............	-2.3^{km}	3	1.6^{km}
Sept. 12 22 ...	−2.1	Adams..........	−2.0		1.3
Sept. 25 21 ...	−2.4	Campbell[8].......	−2.2	10	2.0
Oct. 7 23 ...	−2.9	Bélopolsky[9]......	−2.9	8	3.7
Oct. 27 22 ...	−3.3	Lord and Maag...	+0.6	5	3.7
		Newall..........	−2.6	14	5.7
Mean......	−2.5	Vogel[10]..........	−3.2	13	3.3
		Newall..........	−4.6	5	5.5

β *LEPORIS*

Slipher		Other Observers			
Date, 1905	Velocity	Observer	Velocity	No. of Plates	Range
Oct. 3^{d} 0^{h}...	-12.8^{km}	Frost............	-12.2^{km}	1	$...^{km}$
Oct. 12 23 ...	−13.2	Adams..........	−12.6		
Oct. 27 23 ...	−13.0				
Mean......	−13.0				

1 "Spectrographic Observations of Standard Velocity Stars (1902–1903)," *Astrophysical Journal*, **18**, 273, 1903.

2 *Ibid.*, **15**, 24, 1902.

3 *Ibid.*, **8**, 150, 1898.

4 *Monthly Notices*, **63**, 298, 1903.

5 *Astrophysical Journal*, **21**, 297, 1905.

6 *Monthly Notices*, **65**, 651, 1905.

7 See footnote 2, page 339.

8 *Lick Bulletin*, No. 4, p. 24.

9 *Astrophysical Journal*, **19**, 85, 1904.

10 *Ibid.*, **13**, 322, 1901.

β GEMINORUM

Date, 1905	Velocity	Observer	Velocity	No. of Plates	Range
April 7^d 17^h...	$+3.4^{km}$	Frost............	$+3.2^{km}$	3	0.6^{km}
Oct. 8 0 ...	$+3.2$	Adams..........	$+3.7$		0.2
Oct. 15 1 ...	$+3.4$	Lord and Maag ..	$+5.3$	5	5.4
		Bélopolsky.......	$+3.4$	9	1.4
		Newall..........	$+2.0$	6	3.0
Mean......	$+3.3$				

α BOÖTIS

Date, 1905	Velocity	Observer	Velocity	No. of Plates	Range
April 14^d 19^h...	-5.5^{km}	Frost............	-4.7^{km}	5	1.3^{km}
Aug. 12 16 ...	-4.0	Adams..........	-4.9		0.9
Aug. 15 16 ...	-4.4	Bélopolsky.......	-6.1	9	3.3
Aug, 29 16 ...	-5.0	Lord and Maag...	-3.2	7	3.2
Aug. 31 16 ...	-4.5	Frost and Adams[1]	-4.3	8	1.8
		Newall..........	-5.8	5	2.7
		Newall..........	-6.6	19	4.5
Mean......	-4.7				

β OPHIUCHI

Slipher		Other Observers			
Date, 1905	Velocity	Observer	Velocity	No. of Plates	Range
July 15^d 18^h...	-11.9^{km}	Frost............	-11.3^{km}	3	0.8^{km}
Aug. 15 18 ...	-10.8	Adams..........	-10.9		0.7
Sept. 8 17 ...	-11.3	Newall..........	-15.9	2	1.9
Mean......	-11.3				

γ AQUILAE

Date, 1905	Velocity	Observer	Velocity	No. of Plates	Range
July 5^d 21^h...	-2.7^{km}	Frost............	-1.4^{km}	3	0.7^{km}
July 7 20 ...	-2.3	Adams..........	-2.2		1.0
July 15 20 ...	-1.3	Bélopolsky.......	-2.0	10	3.8
		Newall..........	-1.9	4	4.2
Mean......	-2.1				

ε PEGASI

Date, 1905	Velocity	Observer	Velocity	No. of Plates	Range
July 14^d 21^h...	$+6.1^{km}$	Frost............	$+6.2^{km}$	3	0.5^{km}
Aug. 10 21 ...	$+5.5$	Adams..........	$+6.2$		0.4
Sept. 6 19 ...	$+7.3$	Campbell[2].......	$+5.7$	4	1.2
Sept. 27 17 ...	$+5.6$	Bélopolsky.......	$+6.0$	7	1.4
		Lord and Maag...	$+6.1$	5	5.8
		Newall..........	$+3.3$	3	2.6
Mean......	$+6.1$				

[1] *Publications of the Yerkes Observatory*, Vol. II, Part 4, p. 35, 1903.

[2] *Loc. cit.*

γ *PISCIUM*

Sept. 27d 20h...	−11.8km	Frost............	−10.7km	3	0.4km
Oct. 27 18 ...	−11.0	Adams..........	−11.1		1.1
Nov. 2 17 ...	−11.1				
Mean......	−11.3				

γ *CEPHEI*

Oct. 12d 21h...	−40.6km	Frost............	−41.0km	3	1.0km
Oct. 27 21 ...	−42.2	Adams..........	−41.4		0.2
Nov. 2 20 ...	−43.0	Bélopolsky.......	−39.9	4	2.7
Mean......	−41.9				

As regards the quality of the plates, the velocity of γ *Cephei* is subject to the greatest inaccuracy, due to the weak character of the last plate. The velocity of γ *Aquilae* is also somewhat uncertain, owing to lack of knowledge of the wave-lengths of the *Mo* lines, there being apparent disagreement between the arc[1] and spark values.

Comparison of my results with those of other observers seems to point toward slightly greater negative values for my velocities.[2] But as this depends largely upon the value got for γ *Cephei*, the most discordantly observed star of the ten, I consider it only apparent and due to accidental causes. It might, however, be interesting in this connection to point out that there is a slight difference between the arc wave-lengths[3] of the *V* lines (λ 4300–4500) and Rowland's solar wave-lengths of the lines assigned to *V*, the latter being about 0.0025 tenth-meters greater than the former.

The performance of the 24-inch glass has been, in these observations, entirely satisfactory, as may be judged from a comparison of the exposure times with those of the same stars by Frost and Adams with the great Yerkes refractor. The altitude of this observatory and the transparency of the sky must contribute very greatly

[1] The wave-lengths of the *Mo* lines in the arc were published by Hasselberg in the *Astrophysical Journal*, **17**, 20, January 1903.

[2] Mention should be made here that Professor Lord has called attention to the fact that his and Mr. Maag's velocities are systematically too large positive by about two kilometers.

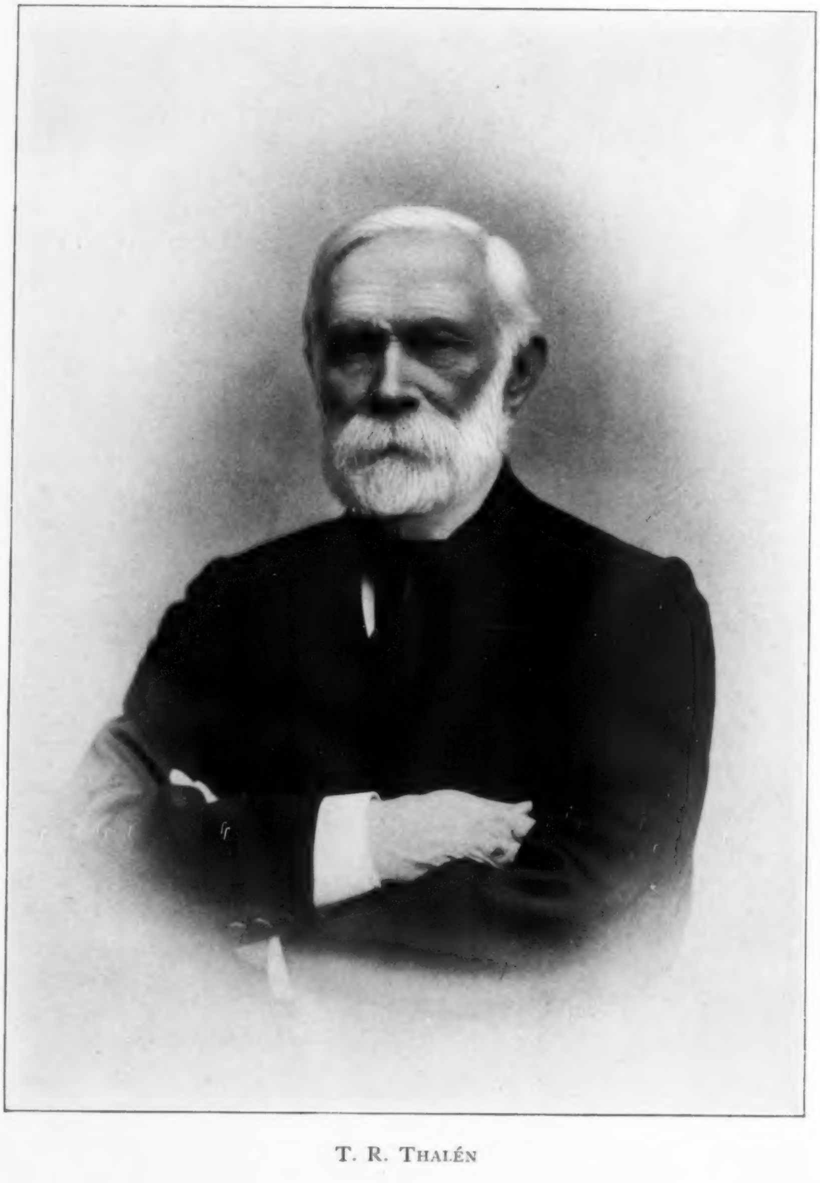
[3] Rowland and Harrison, *Astrophysical Journal*, **7**, 273, 1898.

to the light-power of the equipment. Under fair conditions, with good guiding, satisfactory spectrograms of *α Persei*, for example, would be made (through a 0.025 mm slit) with a 15-minute exposure. My last plate of this star was given that length of exposure and was amply timed, whereas the shortest exposure given this star with the Yerkes equipment was 30 minutes. My earlier plates of this series were, in general, rather over-timed.

In conclusion, I wish to acknowledge my indebtedness to Professor Lowell for encouragement in carrying on these observations, and to Mr. J. C. Duncan, fellow in this observatory, for checking the reductions to the Sun and assisting in preparing the tables for the press.

LOWELL OBSERVATORY,
FLAGSTAFF, ARIZ.,
November 7, 1905.

PLATE XI



T. R. Thalén

Minor Contributions and Notes

TOBIAS ROBERT THALÉN

Tobias Robert Thalén was born on December 28, 1827, in Köping, Sweden. His parents were Jacob Thalén, principal of the school in that place, later pastor in Fläckebo, and his wife, Maria Elizabeth Weijel. After concluding his studies at the school and gymnasium in Westerås, he entered the university at Upsala in 1849, where in 1854 he became a candidate in philosophy, and later in the same year received the degree of doctor of philosophy. Thalén's first scientific work was in the field of mathematics and astronomy, and he became in 1856 docent in astronomy. From 1856 to 1859 he carried on his physical and mathematical studies in England, France, and Germany, and after his return he became docent in physics, and in 1861 adjunct in physics and mechanics at the University of Upsala. For the year 1869–1870 he held the professorship of general and applied physics at the technical school at Stockholm. We find Thalén in the following year again at Upsala, where he was professor of physics and mechanics. On December 19, 1873, Thalén was appointed as the first occupant of the especially established chair of mechanics at the University of Upsala. But in the following year, on August 6, after the sudden death of Ångström, he became professor of physics, and retained this office until he retired on September 1, 1896.

Thalén was one of the most distinguished professors of his time at the University of Upsala. His lectures were characterized by clearness and elegance, and several of his students have become prominent in physics. Thalén also took part in the conduct of the University, in addition to being a member of the Consistorium. From 1883 to 1896 he was a member, and from 1890 to 1896 chairman, of the select committee of the Board of Finances of the University, and from 1889 to 1891 he was *Prorector*. He was also a leading spirit in the Royal Society of Sciences at Upsala, of which he was the librarian from 1860 to 1902, and permanent secretary from 1880 to 1901, thereafter an honorary member. From 1885 to 1899 he was a member of the international metrological committee at Paris, and he took part in numerous meetings of the committee at Breteuil; he was also Sweden's delegate at the metrological conferences at Paris in 1889 and 1895, and he officially transported from Paris to Stockholm the pro-

totypes of weights and measures prepared for Sweden. On October 18, 1901, he was elected an honorary member of the metrological committee. From 1900 to 1903 he was one of the five members of the Nobel committee for physics, which had the duty of dealing with all questions concerning the assignment of the Nobel prize for physics, and of submitting to the Academy of Sciences at Stockholm nominations of those to receive the prize.

Thalén's scientific activity in the domain of physics concerned itself in part with the study of electricity and magnetism and in part with optical observations, but particularly with spectroscopy. His methods of finding deposits of iron ore by means of magnetic measurements have been recognized as of practical significance, and were awarded the medal of the first class of the geographical society by the International Congress of the Geographical Sciences at Paris in 1875. His most important contributions were in the field of spectroscopy. While Ångström was occupying himself with the solar spectrum in general, and in particular with the determination of the wave-lengths in this spectrum, Thalén made measurements of the wave-lengths of the lines of several metals. In this way the value of Ångström's *Spectre normal du Soleil* was still further increased, as the origin of a large part of the Fraunhofer lines could be established with certainty. In a yet greater measure is Thalén's memoir *Sur le spectre du fer obtenu à l'aide de l'arc électrique* (Upsala, 1885) of value as a supplement to the *Spectre normal du Soleil*. It is well known that certain deviations were soon found between the wave-lengths determined by Ångström, and by other physicists, which were of such an order of magnitude that Ångström had himself taken steps to find their cause, but his untimely death prevented him from obtaining better values for his wave-lengths. In the memoir just mentioned, however, Thalén established the fact that these deviations for the most part depend upon the inadequate accuracy of the comparison made in 1866 at Paris between the *mètre à traits* of the Physical Laboratory at Upsala and the *étalon prototype du Conservatoire des arts et métiers*. In his later memoir, *Sur la détermination absolue des longueurs d'onde de quelque raies du Spectre Solaire* (Upsala, 1898), Thalén investigated this question still more thoroughly and found a more precise correction for Ångström's wave-lengths, which brings them into almost exact agreement with the wave-lengths determined by Michelson and Benoit by interference methods. It is true that doubts have been raised as to this method, but it nevertheless appears as though it had been brought into the forefront at the meeting in Oxford of the International Union for Co-operation in Solar Research. In any case, these two investigations

are witnesses to the exemplary accuracy of Thalén's measurements. Finally, Thalén extended his spectroscopic investigations to several newly discovered or rare substances, and, in conjunction with Ångström, to the spectra of the metalloids.

Thalén's services to science were rewarded by membership in numerous learned societies, and the Royal Society of London awarded him the Rumford gold medal; he frequently received awards from Swedish learned societies. It is hardly necessary to mention that numerous orders were bestowed upon him.

Thalén married in 1862 Tonny Carolina Kraak, and one daughter was born from this marriage, who is now the wife of the secretary of the University of Upsala, J. von Bahr.

As appears from what has been said, Thalén was to be called a fortunate man in many respects, and when he requested to be allowed to retire, there seemed to be much to promise him a quiet and peaceful old age. But all this changed in 1901, for in this year his wife was taken from him after a brief but severe sickness and a consequent operation. In the winter of 1903 he himself suffered a fracture of the hip bone from a fall on an icy street. From that time on he was not only a deeply bowed, but even a broken man. On July 27, 1905, he was released by death from his cares and sorrows.

N. C. Dunér.

Upsala,
October 18, 1905.

DE WITT BRISTOL BRACE

On October 2 occurred the death of DeWitt Bristol Brace, professor of physics in the University of Nebraska. By his valuable published researches and by the administration of his professorial office he had won for himself, before his premature death, a prominent position among the physicists of this country.

Professor Brace was born in Wilson, N. Y., on January 5, 1859. He was prepared for college in Lockport, N. Y., and was graduated at Boston University in 1881. After graduation he spent two years at Johns Hopkins University under Rowland, and two years at the University of Berlin under Helmholtz and Kirchhoff. In Berlin he began the series of optical researches, to which his life was devoted, by a study of the magnetic rotation of the plane of polarization, and published the results of his work in his inaugural dissertation, when he received the doctor's degree in 1885. This first paper was an earnest of the work which he was to do in the

future. It is replete with discoveries and suggestions for new work, and was highly commended by Helmholtz for its originality.

After his return to this country he was for a year an assistant professor at the University of Michigan, and soon afterward took up the work at the University of Nebraska, as professor of physics, which for seventeen years, until his death, he conducted with such conspicuous success. From the beginning he felt that his duty as professor was not limited by his courses of instruction, but that he was also bound to promote original research. He had the highest university ideals. To his enthusiasm and to his stimulating influence is largely due the great number of physical investigations which have been carried on in the University of Nebraska in recent years. The new physical laboratory of that university was planned by him especially for research, and he looked forward to years of happy labor in it with his colleagues and his friends. Most appropriately, this laboratory, which was so much the product of his mind and heart, will be named after him, and will no doubt illustrate for many years to come, by the work which proceeds from it, the inspiring example of its designer.

Brace's own contributions to physical science were almost exclusively in the domain of optics. By the invention of his sensitive-strip polarizer, and his half-shade elliptic polarizer, he extended the range of observation far beyond that previously attained, and he devised and partly executed many experiments in which this increased sensitiveness could be used in the study of fundamental optical problems. Returning to the question which he dealt with in his first published paper, he succeeded in showing that the beam of polarized light which undergoes rotation in a magnetic field is susceptible of resolution into two circularly polarized beams. He showed that, to a very high order of sensitiveness, no effect is impressed upon a ray of light by a magnetic field, if its lines of force are at right angles to the ray. He showed that, up to the third order of the ratio of the velocities, no double refraction could be observed in a medium due to its motion through the ether. He planned and tested a method for determining the velocity of light, from which he expected still greater accuracy than that attained in the classical researches of Michelson and Newcomb. He executed several repetitions, with greatly improved instrumental appliances, of classical experiments bearing on the fundamental question of the relative motion of matter and the ether. It is sad to relate that much of the work which he laid out for himself remains incomplete. He had planned more extensive investigations of the ether drift, and was only waiting for the completion of his new laboratory to undertake this impor-

tant task. No nobler memorial could be raised to him, nor one more after his own heart, than the execution of these long-meditated plans by those who will take up his labors in the place which he had designed for them.

W. F. MAGIE.

PRINCETON UNIVERSITY,
November 15, 1905.

WALTER F. WISLICENUS

It is with great regret that we record the untimely death, at the age of forty-six, of Walter Friedrich Wislicenus, *Ausserordentlicher* Professor of Astronomy at the University of Strassburg. His observational activity began in 1882, before the completion of his university studies, when he took part in the observations of the transit of *Venus* with the third German expedition. For more than six years thereafter he was assistant in the Strassburg Observatory and largely concerned with meridian-circle observations. He also regularly observed the Sun with the heliometer. His doctor's thesis, *Beitrag zur Bestimmung der Rotationszeit des Planeten Mars*, was published in 1886. He became *Privatdozent* in Strassburg in 1888, qualifying with his paper on *Untersuchungen über den absoluten persönlichen Fehler bei Durchgangsbeobachtungen*. He was appointed professor in 1894. He was a successful teacher, and his public lectures were characterized by their clearness.

It was a matter of regret to his friends that circumstances did not put him in a position where he could become a practical observer in the field of astrophysics, which held for him a very great interest. As a result of this, his scientific activity, aside from teaching, was more directed toward literary and bibliographical lines. His *Tafeln zur Bestimmung der jährlichen Auf- und Untergänge der Gestirne* constituted the twentieth volume of the publications of the *Astronomische Gesellschaft*. His *Astronomische Chronologie* (1895) is a book of value to historians and archæologists, as well as to astronomers. He also contributed important articles to Valentiner's *Handwörterbuch der Astronomie*, and he wrote several booklets in popular scientific series.

During recent years he had devoted himself with great diligence to the editorship of the *Astronomisches Jahresbericht*, established by himself, and now in its seventh volume. His service in founding this valuable bibliography of current astronomy was a great one, and will be increasingly appreciated as time goes on.

He was of charming personality, and in his quiet dignity a fine illustration of the gentleman and scholar.

F.

SOME REMARKS ON DR. O. C. LESTER'S CONTRIBUTION "ON THE OXYGEN ABSORPTION BANDS OF THE SOLAR SPECTRUM"[1]

Owing to some delay in delivery, this paper did not come under my notice until six months after date of publication; consequently a number of inaccuracies contained therein have, in the meantime, remained unchallenged.

I refer to some comments on my paper on the same subject in the *Proceedings of the Royal Society of 1893.*

This latter, which is mostly of a tabular nature, describes the analytical process which led to a formula expressing the relation between the lines composing the absorption bands A, B, and α; its application to the resolution of the congested groups forming the heads of these bands into pairs; and the general subdivision of all the bands into series.

The apparent complexity of the head portions is shown to be due to the overlapping and interlacing of several pairs near the edges of the bands.

The resolution is illustrated by means of a graphical construction in which the axis of y at the origin is a tangent at the vertex of a parabolic curve, the axis of x coinciding with the scale.

The extensions of the lines of a series are shown to intersect the curve at uniformly increasing distances from the axis of x, and the formula referred to is derived from the known properties of the curve.

The two head series are shown to be distinct and independent of the two series forming the trains, the entire band being composed of at least four series.

The greater intensity of certain head lines, the gradual variation in the separation of the components of pairs, and other characteristics which are the natural consequence of such independence, are also mentioned.[2]

All this, which, from a spectroscopic point of view, has become a matter of ancient history, can hardly be presented to the readers of the *Astrophysical Journal* as a new discovery. I feel that I ought not to overlook any such implication.

On p. 92 the following statement is made: "In his study of the single band by means of the parabola, Higgs shows a smooth curve connecting the lines of the head and tail series as if they were parts of the same band," etc.

I reply simply, but emphatically, that I do not show any such smooth

[1] *Astrophysical Journal*, **20**, 81, September 1904.

[2] A limited number of copies are still available for distribution.

curve connecting the lines of the head and train, but, on the contrary, show plainly that the head and train series are in every case independent of each other.

In the text of the original memoir it is distinctly stated that each band is divided into four series. Correspondingly in the tables the parameters of four different curves are given for each band, the four vertices of which occupy as many different positions on the wave-length scale.

On page 82 appears this remark: "Higgs confines himself to the study of the relations of the lines of a single band, taking B as an example."

It is not clear what can be the object of this statement, for not only were the a and B bands fully discussed, as far as the lines could be measured with any degree of accuracy, but several series of the A band which were not previously known to exist were examined and tabulated.

The faint band in the green beyond D, which is invisible except by the aid of the most powerful instruments, was unknown at that time; but the following extract from a description of my *Photographic Studies* (1893) is evidence that the principal line was found to possess all the characteristics of absorption by the oxygen of our atmosphere:

No. 9.—N.E. wind, dry. Below freezing. Air lines extremely faint. One line, λ 5789.4, is unaffected by the low temperature and by comparison with other low Sun sections, such as 10 and 86, evidently maintains an intensity proportional to the Sun's altitude. The position is in close agreement with that of an absorption band for liquid oxygen as observed by Egoroff, Liveing and Dewar, and also with the hypothetical position for a fourth group in sequence with A, B, and a.

The paragraph on page 82 concludes as follows: "There are two parallel parabolas corresponding to the two series in each band, the vertices coinciding with the beginning of each series."

As a matter of fact, the elements of four different parabolas are given, corresponding to the four series in each band. The last part of the sentence is misleading, if it is meant to convey that the vertices coincide with the first lines of the series instead of the origins. The foregoing distinction, as I will endeavor to show, has an important bearing on the construction of a general formula, not only for the oxygen absorption bands of the solar spectrum, but for any other spectrum series whose second differences expressed in wave-lengths or wave-frequencies are likewise practically constant.[1]

[1] The extremely minute deviations referred to in the original memoir cannot be taken into account until the measurements can be relied on to within a few thousandths of a tenth-meter.

First, let it be assumed that the initial line coincides with the origin at the vertex; then, from the above-named condition and the nature of the curve, we know that

$$\lambda = v + \frac{1}{p} n^2 \ . \tag{1}$$

But from the condition alone we also know that the wave-length of *nth* line is, in part, the product of the arithmetical progression, $1 + 3 + 5 + \ldots\ldots + r$, that is, n^2 into the semi-constant second difference denoted by b, so that

$$\lambda = A + bn^2 \ . \qquad \text{(2) Deslandres' formula}$$

In applying the above to wave-frequencies a change of signs becomes necessary. No. 2 is applicable to bands of many gaseous spectra whose lines at the edges of bands are in close formation. The solar group commencing at λ 3883.5 on Ångström's scale is probably an example.

For bands whose edges are in more open formation there is but one possible case where it can be applied, and that is where all of the first differences happen to be odd multiples of the semi-constant difference b.

The second of the "Secondary Series" in the train of A which I discovered in 1890 furnishes a remarkable and, as far as I know, unique example of its application; here the first differences are odd multiples of the semi-constant difference.

It may here be remarked that missing lines of a series, if any, are necessarily included in the reckoning from the origin.

In general, the first differences are in excess of the odd multiple, as shown in the appended column, from which it will be seen that the excess is also a constant:

$$\begin{array}{l} \text{Origin} \\ \text{—} \\ \quad b+k \\ \text{—} \\ \quad 3b+k \\ \text{—} \\ \quad 5b+k \\ \text{—} \\ \quad \cdot \quad \cdot \quad \cdot \\ \quad \cdot \quad \cdot \quad \cdot \\ \quad \cdot \quad \cdot \quad \cdot \\ \quad rb+k \\ N \end{array} \left.\vphantom{\begin{array}{l}1\\1\\1\\1\\1\\1\\1\\1\\1\\1\\1\end{array}}\right\} \text{sum} = kn + bn^2 \ . \tag{3}$$

In this case the first line of a series cannot coincide with the vertex or

origin, and the expression for the wave-length is a modification of (1), or

$$\lambda = v + \frac{1}{p}(n \pm c)^2 \,, \qquad (4)$$

which is applicable to every possible case.

This is my parabolic formula, which, reduced to the straight line as in (2), becomes

$$\lambda = O + b(n \pm c)^2 \,, \qquad (5)$$

where O, the origin, has the same value as V, but does not coincide with A, denoted as the first line of the series.

In practice this difference between V and A requires to be known; denote it by x, which we know is $= \frac{y^2}{p} = b\,y^2$ from the nature of the curve and the equality of b and $\frac{1}{p}$, and as $k = 2b\,y$ and $y = \frac{k}{2b}$, then $x = \frac{k^2}{4b} = \frac{(f-b)^2}{4b}$, where f denotes the first difference.

Formula (4) was used simply because of its direct application to the graphical construction given in the memoir; but the mechanical and physical sciences supply us with numerous other instances in which one quantity varies as the square of another, several of which might serve as illustrative principles.

As an example, the reader may conceive a point to move along the scale with a uniformly increasing speed, and the spaces between the lines of any series will be described in equal intervals of time; but whatever form the expression assumes, the coefficient of n^2 has one signification and one only: it is the inseparable accompaniment of the hypothesis with which we set out.

In dealing with the discrepancies between the measurements and calculations on page 95, Dr. Lester states that the character of the variations plainly indicates that Deslandres' constant b is not really a constant, and in the concluding pages proposes to amend Deslandres' law by ascribing to that factor as many values as there are lines in a series; and finally on page 98, after discarding it altogether, he adopts two other constants which have no meaning whatever except that they combine in producing an approximate agreement between the measures and calculations in the formula $N = a + kn + c^{-1}n^2$.

It must be obvious that this or any other formula which does not involve the semi-constant second difference as a coefficient of n^2 has no *raison d'être;* the amendment then resolves itself into a *reductio ad absurdum.*

If it is considered desirable to involve both first and second powers of n, why not at once apply the ready-made textbook formula for uniformly accelerated motion? In which case we have

$$N = a + kn + bn^2 , \tag{6}$$

where b retains its constancy and k the signification already assigned to it in (3). In applying (6) to the wave-length scale the terms are positive, and the calculations would agree precisely with those of my tables, but the numbering of the lines of a series from 0 to n would not, of course, include the missing steps from 0, the initial line, to the origin.

The lines of Dr. Lester's continuation table on page 92 evidently constitute the first three pairs of my "Secondary group" which is independent of both head and tail of the main band.

GEORGE HIGGS.

LIVERPOOL,
September 15, 1905.

SECOND NOTE ON "ORTHOCHROMATIC" PLATES

The "sensitiveness-curves" in Fig. 3 accompanying the present paper were plotted from negatives obtained under precisely similar conditions to those described in my "preliminary note."[1]

In considering the series recording the selective sensitiveness of the Cramer "Slow Isochromatic" plate an interesting condition was observed which, in brief, amounts to a reversal of curve according to whether "under" or "normal" exposure be considered.

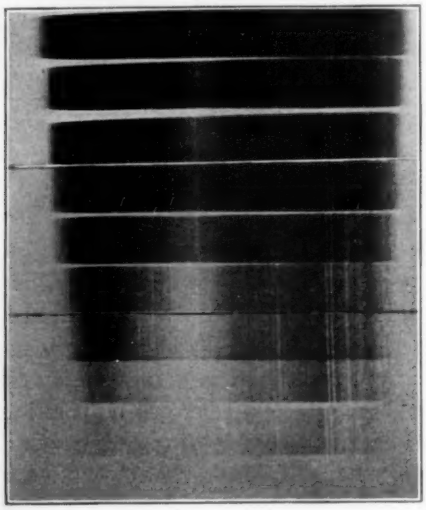


FIG. 1

In the record of this plate (Fig. 1) it will be noted that beginning with the 5 seconds exposure, up to and including that of 30 seconds, the maximum sensitiveness lies decidedly in the violet about λ 3900–4100. With the 1 minute exposure, however, the yellow-green sensitiveness is slightly in excess of the former, and gains in density very rapidly with increasing exposure, until at 8 minutes it is far ahead and has then reached

[1] See p. 153.

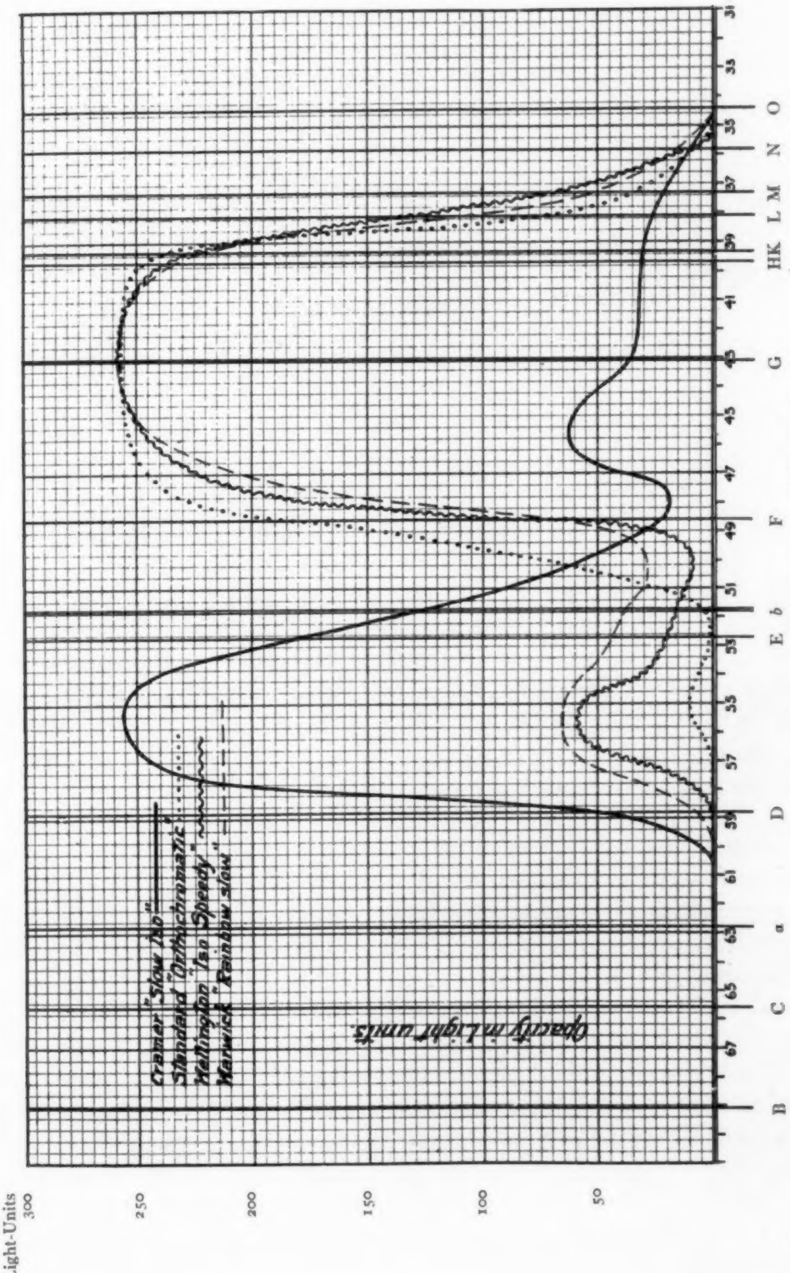


FIG. 2.—Sensitiveness-Curves in Light-Units.

the point of greatest allowable opacity. In the meantime the blue-violet has but slightly increased.

The dye incorporated in the emulsion during the preparation of the plate stains it with a heavy greenish-orange hue, which shows a definite absorption band in the yellow-green from λ 5400–5800; while in the violet the absorption is very strongly marked, shading off gradually in the blue. The sensitiveness-curve for normal exposure is therefore resultant from a combination of emulsion and "light-filter."

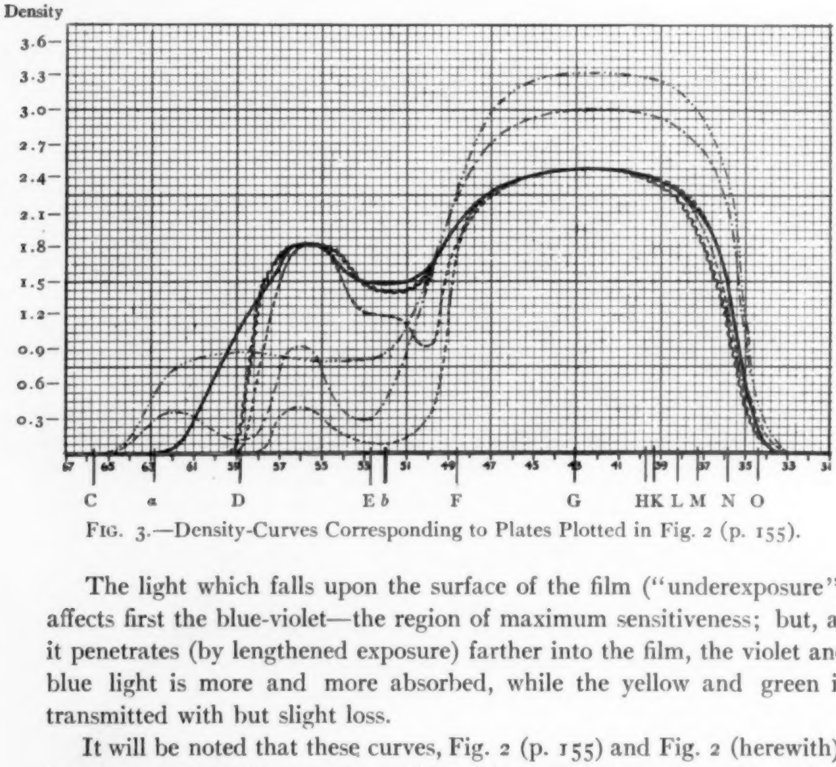


FIG. 3.—Density-Curves Corresponding to Plates Plotted in Fig. 2 (p. 155).

The light which falls upon the surface of the film ("underexposure") affects first the blue-violet—the region of maximum sensitiveness; but, as it penetrates (by lengthened exposure) farther into the film, the violet and blue light is more and more absorbed, while the yellow and green is transmitted with but slight loss.

It will be noted that these curves, Fig. 2 (p. 155) and Fig. 2 (herewith), have been plotted with "opacity in light-units." This differs from the method of Hurter and Driffield, who measure opacity, but plot *density*. The investigations of these workers[1] have proven that in a theoretically perfect negative the quantities of silver reduced at different points are proportional to the logarithm of the light producing them; the deposit of silver (density) representing the amount of chemical work accomplished by the light. By

[1] *Journ. of Soc. of Chem. Industry*, May 1890; also *Photo-Miniature*, **5**, No. 56, Nov. 1903.

plotting these spectrum negatives as "opacity in light-units" the curves serve as an indication of the relative exposure for pure color. At the same time they should also be plotted as densities, for, the transparency of the light being reduced by the density, such a curve is the measure of the printing value (Figs. 3 and 4).

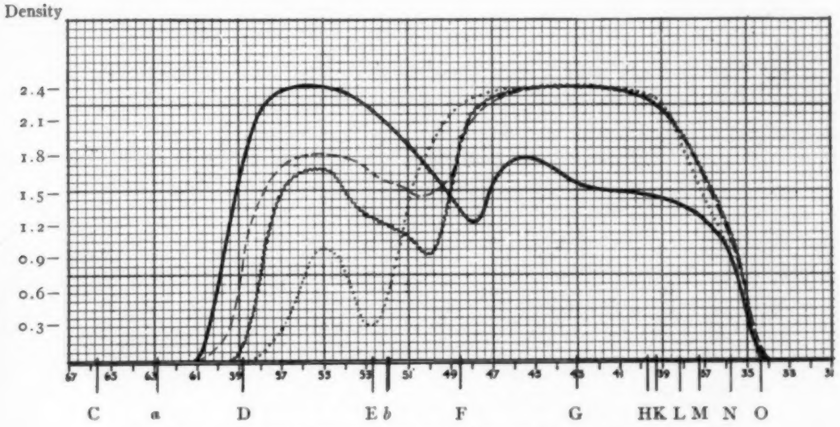


FIG. 4.—Density-Curves Corresponding to Plates Plotted in Fig. 2.

As a check upon the opacity estimation of these curves it was thought advisable to adopt some method of "proving" them. A density-curve was therefore selected (Cramer "Instantaneous Isochromatic") which had been plotted from the opacity-curve already published,[1] and which should

FIG. 5

be, theoretically, exactly the inverse of the original. This was mounted upon a sheet of opaque paper and its area carefully cut out, then placed in a camera, and an image projected of a size comparable with the original negative. This last adjustment was readily effected by making pinholes through the paper mask at the positions of the Fraunhofer lines (abscissæ) and focusing the bright images to size. By means of a plate swinging vertically the image of the curve was caused to impress itself with varying

[1] See p. 155.

density, the pinholes being distinctly shown as slightly darker lines crossing the negative of the artificial spectrum thus obtained.

This negative was found to be closely comparable with the original spectrum negative, when due allowance was made for the effect of the Fraunhofer lines in the latter. Comparison prints are shown in Fig. 5, in which one-half of the height of the artificial spectrum has had the lines drawn in by hand, while the remaining half is untouched.

The result of the speed tests for the plates represented in this second note is (while still taking the Cramer "Instantaneous Isochromatic" as 1.0) as follows:

Standard "orthochromatic"	= 0.75
Cramer "slow isochromatic"	= 9.00
Warwick "Rainbow" (slow)	= 2.00
Wellington "Iso speedy"	= 1.17

Thus it would appear that the "slow isochromatic" has a speed of one-ninth that of the "instantaneous isochromatic."

ROBERT JAMES WALLACE.

YERKES OBSERVATORY,
October 27, 1905.

NOTE ON THE EVOLUTION OF THE SOLAR SYSTEM

In the October number of the *Astrophysical Journal*, Professor Moulton, in the leading article, attacks the idea that the retrograde revolution of *Phoebe* may be explained by the hypothesis that *Saturn* itself formerly revolved in a retrograde direction; that the solar tides reversed this rotation, so that the planet presented for a time only one face to the Sun; and that subsequent condensation accelerated its speed to the velocity which it now possesses.

In all that he says of this supposition I quite agree with him, although I am surprised that he should have thought it worth while to devote so much space to disproving an explanation so obviously improbable. What I fail to understand, however, is why he should associate my name in any way with this ancient theory. Perhaps when it was propounded by Kirkwood in 1864[1] it did not seem so improbable as it does today, but that was a good while ago.

How Professor Moulton should have so completely missed the thread of my explanation I cannot understand, but would suggest that he should read some of my papers on the subject. The theory of planetary inversion has been before the public now for the last twelve years. It was propounded in order to explain some peculiarities of *Jupiter's* satellites, and the anomalous revolution of the satellites of *Uranus*, a revolution which

[1] *Am. Jour. Sci.*, **38**, 1.

no other theory has ever even attempted to explain, before or since, so far as I am aware.

When the retrograde revolution of *Phoebe* was discovered, it was found that the inversion theory would fully explain it as it stood, without modification. Indeed, *Phoebe* furnished a very pretty illustration of it. Incidentally it also explains the inclined orbits of the sixth and seventh satellites of *Jupiter.*

I would suggest to Professor Moulton that when he has read one of my articles, he should procure a gyroscope and watch the wheel gradually shift its plane—it is a rather interesting sight.[1] At first it will, for instance, be parallel to the plane of the orbit of the satellite of *Neptune*, then of *Uranus*, then of *Saturn*, and finally, when the planes of revolution and rotation again coincide, to that of *Jupiter.*

WILLIAM H. PICKERING.

October 18, 1905.

AN APOLOGY AND AN EXPLANATION

1. I desire to apologize to Professor W. H. Pickering for having misinterpreted his views in my paper on the evolution of the solar system. But there was no hint in the paper that the theory of tidal retardation was original with him. It has been well known since the time of Delaunay; and so well known since the researches of Darwin in 1878 that it was not deemed necessary to refer to its origin. The statements were intended to mean simply that Professor Pickering applied this idea to the evolution of the Saturnian system. Since he denies having had any reference to it, I must express my deep regret that I ascribed to him such views.

2. I wish to make a few comments on the dynamics of the question, and to show that, under the hypotheses adopted by Professor Pickering, the only effect on the rotation of the planet would be precisely that which I represented him as having had in mind. Since in all his papers he used general language with vague references to the gyroscope, rather than the precise terminology of technical dynamics, his ideas were not perfectly clear to me. My excuse for ascribing to him the views which I did, is that, while I was not absolutely sure from his language what he had in mind, I assumed that his conclusions followed from the hypotheses which he adopted.

The problem in question is to determine the effects on the rotation of a planet of the attraction of the Sun for the tides which it has raised upon the planet. The first principle of the dynamics of rigid bodies is that all the forces which act upon a body may be resolved into three rectangular components applied to its center of gravity, and three couples about three

[1] *Nature*, **71**, 608.

rectangular axes. Since the rectangular components do not affect the rotation, they may be omitted from this discussion.

Let us take the x and y-axes in the plane of the orbit of the planet, and the z-axis perpendicular to this plane. The couple considered by Professor Pickering is the one around the z-axis. This follows from the fact that he says the force which he is considering is perpendicular to that which produces the precession.

Now consider the rotation. Just as any translation may be resolved into three rectangular components, so any rotation may be resolved into rotations around three axes. The rate of rotation around the x-axis may be represented by a vector from the origin along the x-axis, which may be called *Oa*. The rotations around the other axes may be represented similarly by *Ob* and *Oc*. The instantaneous axis of rotation has the direction of the resultant of these three vectors, and the rate of rotation is proportional to the length of the resultant.

The second principle of the dynamics of a rigid body is that the rate of change of rotation around an axis is proportional to the couple around that axis. This means that the couple around the z-axis changes the rate of rotation around the z-axis, and does not affect the rotations around the other axes.

Consider the rotation of the planet. Suppose it is rotating around an axis perpendicular to the plane of its orbit. Then the vectors *Oa* and *Ob* are zero, while *Oc* extends in the negative direction from the origin. A slightly lagging tide will give a positive couple around the z-axis. This will increase *Oc* algebraically. If it continues long enough *Oc* will become zero, when the planet will have no rotation. After that *Oc* will become positive, and the rotation will be positive. This is the ordinary statement of the case.

Suppose now that the rotation is around any axis, but that the component of rotation around the z-axis is negative. In this case *Oa* and *Ob* are not zero. The couple around the z-axis will act precisely as before, for its effects are independent of the rotations around the x and y-axes. That is, it will change the rotation around the z-axis just as it would if there were no rotations around the other axes. Also, it will not change the other rotations. Hence it can never bring the planet's equator into the plane of its orbit. Since the question is respecting the change of moment of momentum around the z-axis from negative to positive, it follows that there is no reason whatever for introducing the rotations around the x and y-axes. The only result of doing it is to lead to a confusion of ideas when the problem is not treated by the methods employed in dynamics. It is easy to point out the source of the confusion. When the rotation around the z axis had become zero, there still remained a rotation, for

the rotations *Oa* and *Ob* retained their original values. Hence the body never stopped rotating, while its axis of rotation turned over. But this does not mean that the body turned over, or that its rate of rotation remained unchanged. On the contrary, since the rate of rotation of a body is equal to the resultant of its three components, it decreased until the z-component became zero, and then increased again. The whole thing corresponds to the fact that if a body is projected upward not vertically, it will fall back to the Earth without its velocity ever having become zero. Just as the influence of the Earth's gravitation on the vertical component is independent of the other components, so the influence of the couple around the z-axis is independent of the other components of rotation. Therefore their introduction has added nothing to the problem except possibly a little misunderstanding of it.

F. R. MOULTON.

THE UNIVERSITY OF CHICAGO,
November 8, 1905.

REPLY TO PROFESSOR F. R. MOULTON

I have carefully read over Professor Moulton's reply to my letter, and it still appears to me that the effect of the annual tides on a planet having a retrograde rotation will be not simply to stop and then reverse this rotation, leaving its plane unchanged, as Professor Moulton claims, but rather to cause it to turn over, so that the rate of rotation shall be unchanged, while its plane is by this means rendered parallel to the orbit of the planet.

I am sorry to differ from Professor Moulton on a point in such elementary mechanics. The simplest case to consider, it seems to me, is where the rotations about the y and z axes are reduced to zero. We have now only a rotation about the x axis. This is the case, very nearly, of the planet *Uranus* at the present time. Let us now introduce a minute couple tending to cause a rotation about the z axis, due to the annual tide raised by the Sun. The result is to shift the direction of the axis of rotation of the body so that instead of being parallel to x, as before, it is now inclined slightly toward that of z. This may be represented by the component of the vectors in these two axes. The tidal force still acting about the z axis, the axis of the body inclines more and more toward it, until it finally becomes parallel to it.

The last few lines of Professor Moulton's letter seem to me to express this very idea. As he says, the body does not stop rotating, its axis of rotation simply turns over. His comparison to a falling body also seems to me to be an apt one. In the case above stated a body would be projected in a horizontal direction. Its horizontal velocity represents the

vector in the axis of x. It is acted on by a vertical acceleration, corresponding to the couple about z, which finally produces a velocity in a nearly vertical direction. This is the vector in the direction of the axis z.

The two cases are not exactly alike, because the uniform horizontal velocity exhibited by the falling body is not maintained in the other case, nor is the acceleration produced by the tidal forces uniform, since it becomes zero when the axis of rotation of the planet becomes parallel to z. A better analogy would be that of a stone projected horizontally through still water. The direction of motion of the stone through the action of gravity gradually becomes vertical.

I think if Professor Moulton will refer to my paper in the *Astronomische Nachrichten,* **164,** 201, he will there find the subject treated from the dynamical standpoint.

WILLIAM H. PICKERING.

November 12, 1905.

NOVA AQUILAE OF 1905

Following is a list of the plates which I made at Mount Wilson, California, with the Bruce telescope covering the region of the *Nova*, to which Professor Frost called attention in the last number of this *Journal* (p. 270).

The given magnitudes are the smallest shown on the plates in that region. These magnitudes are photographic, and were derived from comparison with reflector photographs of the same region, on which Mr. J. A. Parkhurst had kindly marked certain magnitudes for my guidance. In every case the stars were in the region of bad definition, as no plate was centered quite near the place of the *Nova*. All these plates were made with the 6¼-inch doublet.

1905	Exposure	Lowest Magnitude
June 5	2 52^m	13.5
6	1 43	13.3
July 2	1 58	14.0
7	4 35	14.0
29	0 25	14.0
30	5 30	16.0
Aug. 4	4 30	15.0
23	3 15	*Nova* shown strongly
24	4 0	*Nova* shown strongly

The *Nova* thus appears strongly on the plates of August 23 and 24, but not on any of the other photographs.

E. E. BARNARD.

YERKES OBSERVATORY,
November 10, 1905.

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VOLUME XXII NUMBER 5

THE ASTROPHYSICAL JOURNAL

An International Review of Spectroscopy and Astronomical Physics

EDITED BY

GEORGE E. HALE, Solar Observatory of the Carnegie Institution

EDWIN B. FROST, Yerkes Observatory of the University of Chicago

DECEMBER 1905

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THE

ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

PUBLISHED MONTHLY EXCEPT IN FEBRUARY AND AUGUST

VOL. XXII | DECEMBER 1905 | NO. 5

Editorial communications should be addressed to the Editors of The Astrophysical Journal, Yerkes Observatory, Williams Bay, Wis.

Business correspondence should be addressed to The University of Chicago Press, Chicago, Ill.

Subscription, $4.00 per year. Single copies 50 cents. Postage prepaid by publishers for all subscriptions in the United States, Canada, Mexico, Cuba, Porto Rico, Panama Canal Zone, Republic of Panama, Hawaiian Islands, Philippine Islands, Guam, Tutuila (Samoa), Shanghai. For all other countries in the Postal Union 75 cents for postage should be added to the subscription price.

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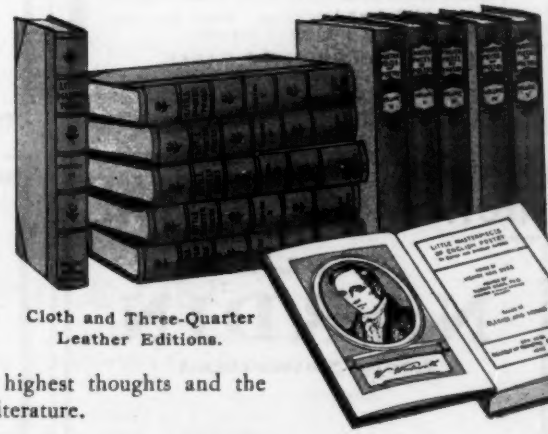

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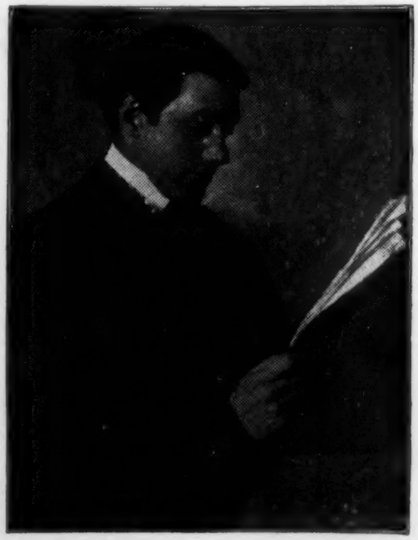

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ORIGIN: The Constructive Bible Studies are the outgrowth of the conviction that the prevailing systems of Sunday-school instruction are insufficient to meet the growing demands of the times.

PURPOSE: Believing the Sunday school to be the great educational branch of the church, the editors of the Constructive Bible Studies have sought to produce a series of religious textbooks based on the fundamental laws laid down by trained educators. One of the most important of these laws is the principle that the curriculum must be adapted to the capacity of the pupils, giving to each grade work which is suited in material and method of treatment to the stage of development of the pupils.

PLAN: The Studies comprise four series, each corresponding to a definite stage of development in the pupil.

THE KINDERGARTEN SERIES

takes up work of a more general character, dealing with the fundamental facts of the Bible and the religious life.

THE ELEMENTARY SERIES

is intended as an aid in broadening the view of the Bible as a whole, and as an introduction to the study of particular books.

THE SECONDARY SERIES

has for its object a closer acquaintance both with the biblical material and with religious concepts.

THE ADVANCED SERIES

has been planned with a view to promoting a more minute examination of the historical data, and naturally invites a discussion of current religious problems and the various attempts at their solution.

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Under the editorial direction of the Classical Department of the University of Chicago, with the co-operation of a number of representative scholars of other institutions; PROFESSOR EDWARD CAPPS, of the University of Chicago, Managing Editor.

Classical Philology is established in the conviction that classical studies in America has so developed during the last quarter of a century as to demand an additional medium of publication, and that the establishment of such a journal will not only meet this need, but will also foster and encourage research, and materially help to raise the level of classical studies in this country. The journal will be devoted to investigations in the languages, literatures, history, and life of Classical Antiquities, and to reviews of current publications in these fields. It will be issued quarterly, in January, April, July, and October. The first number will appear about January 1, 1906. The first volume will contain about 380 pages.

Subscription price, $3.00 a year; single copies, $1.00; foreign subscriptions, $3.50.

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Published under the auspices of the Classical Association of the Middle West and South, and edited by a Board appointed by the Association; PROFESSOR ARTHUR FAIRBANKS, of the University of Iowa, and PROFESSOR GORDON J. LAING, of the University of Chicago, Managing Editors.

The Classical Journal is devoted especially to the interests of teachers of Greek and Latin, as teachers, whether in school or in college work. It will contain articles, editorials, discussions and reviews. This medium of professional communication for all active students and teachers of the Classics will prove, it is believed, a most useful and effective instrument for the improvement of instruction and for the spread of intelligent interest in these subjects, and that through its influence a marked improvement in the standing of the Classics in this country may be confidently expected.

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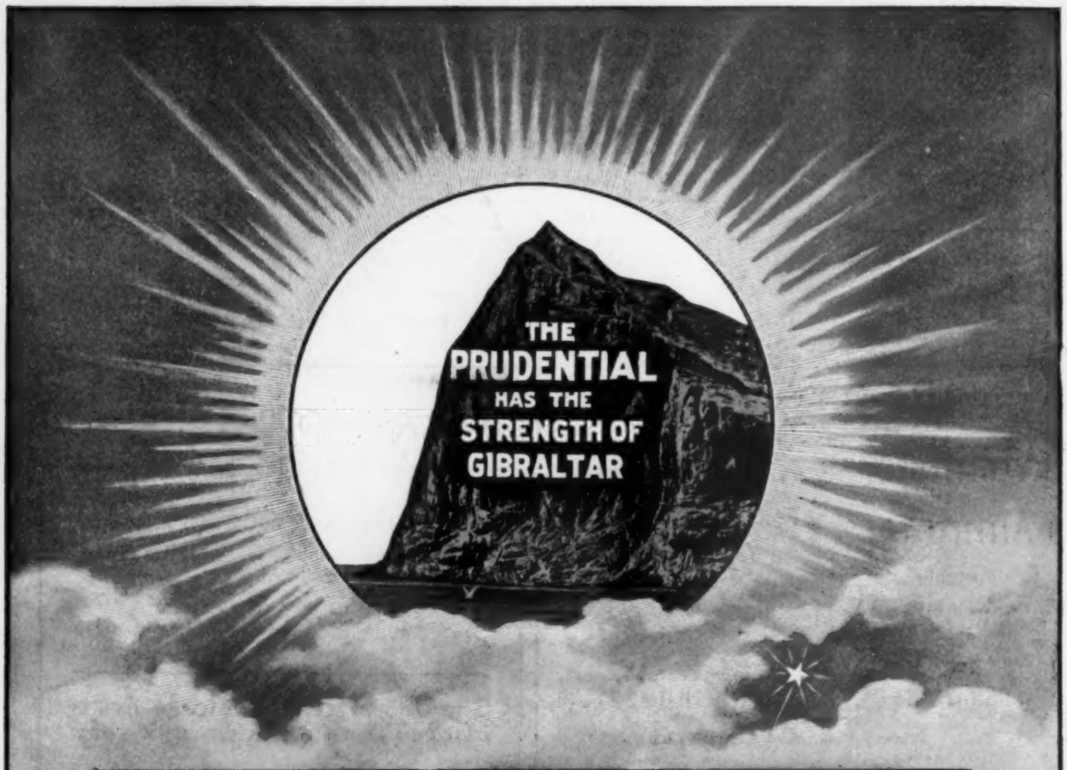

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